TRANSPORTATION RESEARCH RECORD
506

Formerly issued as Highway Research Record

Better Maintenance:

Measuring Quality; Training Personnel; Snow Fences and Deicing Chemicals; Planting and Patching

9 reports prepared for the 53rd Annual Meeting of the Highway Research Board

subject areas
12 personnel management
24 roadside development
31 bituminous materials and mixes
40 maintenance, general

TRANSPORTATION RESEARCH BOARD
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FOREWORD

How can a maintenance organization operate with a budget and manpower that in relative terms are continually diminishing despite continually increasing costs due to inflation, environmental pressures, energy restraints, lawsuits, increasing numbers of heavy axle loadings, and a public that seems unappreciative of the scope of the problem? This RECORD will not answer that question, but it does present a variety of efforts that have been made to cope with the overall problem. The individual papers show an agency how to measure the quality of maintenance being provided by an organization, help the agency to develop maintenance personnel training programs, offer an experimental patching material for consideration, describe results of an investigation of water pollution attributed to maintenance programs, compare alternate deicing chemicals, describe promising roadside plantings for humid regions and a better program of herbicide maintenance, and summarize the results of an in-depth study of snow drifting.

One serious gap in our knowledge is the lack of objective quality standards for maintenance, with such noteworthy exceptions as road roughness and skid measurements. Therefore, the work in Ohio reported here by Miller represents significant progress.

Counterculture values developed on college campuses in the 1960s are now penetrating the rest of society and may be adversely affecting maintenance worker productivity. Job dedication and depression-bred appreciation for the advantage of holding a state job are now lacking. LaRue Delp, Maintenance Engineer for the State Highway Commission of Kansas, in a paper entitled "Philosophy of Managing Personnel" presented in committee as a companion piece to the papers on training in this RECORD, stressed this problem when he referred to a trend toward deemphasizing rigid rules, thus weakening the foreman's and superintendent's authority. Training is one way of compensating for these changes, and the paper by Wilson and Smith, with discussions, provides guidance to accomplishing a training program.

Pavement and structure maintenance continue to be a problem, and pavement potholes, once thought to have been relegated to a position as a minor problem, continue to plague the maintenance profession. Siemens and Amstock report on the early phases of testing an improved patching compound. The results of field trials are promising, and further research is planned.

Three papers in this RECORD should be of interest to chemists and maintenance engineers. Reports by Field et al., Grant, and Stratfull et al. are concerned respectively with potential water pollution from street salting, a comparison of rock salt versus solar salt, and an investigation of alternate deicing chemicals.

Some years ago a commentator on a national television network was critical of the location of a section of I-80 through southern Wyoming; one of his charges was that the new location resulted in greater snow problems than the old location. The problem had been anticipated and arrangements were made to control drifting by snow fencing. Tabler made an in-depth study to assist the state, and some of his findings should be of interest to other designers and to maintenance engineers in snow-belt states. For example, the quantity of snow to be stored can be computed from known and measured variables, and even in the windswept, snow-covered plains of Wyoming the fence requirements do not become intolerably large.

Zak and Kaskeski point to the desirable attributes of flat pea plantings for highway slopes, and Morré describes a minimum-cost and environmentally safe program of herbicide maintenance for Indiana roadsides.

A METHOD OF MEASURING THE QUALITY OF HIGHWAY MAINTENANCE

Edward L. Miller, Operations and Maintenance Administration,
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In 1970 the Ohio Department of Transportation developed a method of measuring the quality of highway maintenance. The purpose was threefold: to measure objectively the quality of maintenance achieved by highway maintenance forces, to establish acceptable standards of maintenance quality, and to provide a means of setting annual district and statewide maintenance performance objectives. The resulting method meets these objectives and is recommended for use by other states. The system utilizes a random sample of highway sections on which identifiable maintenance work items are counted by 2-man survey crews working statewide full time. Ohio uses 2 crews to make surveys quarterly. Work items are counted on 2-mile sections of highway using 13 items that reflect the quality of force-account highway maintenance. The field data are reduced to the number of maintenance work items per mile in each maintenance category for each of the 88 counties in Ohio, and these values are plotted by computer in 3 different forms of bar charts. The bar charts show direct expenditures per lane-mile as well as the maintenance work items per mile. This method of measuring the quality of maintenance provides useful information for all levels of management.

•A MAJOR concern to every highway administration is whether or not the highway system is being maintained at the proper level. The levels at which highways are being maintained at a given time depend on a number of factors; among these are maintenance policies, the efficiency of the maintenance force, and the availability of maintenance funds.

A method is being used in Ohio to measure objectively the quality of highway maintenance. The measurement is based on AASHTO-defined objectives of the maintenance program, namely, the physical preservation of the highway and the provision of safe, convenient, and economical highway transportation. Field measurements for each highway element or activity are used as direct measures of quality by conversion to units per mile. The results of the survey method in units per mile are plotted by computer in bar chart form for use by all levels of management. From the graphic presentation of field measurements, Ohio's 88 county superintendents can quickly and easily see what type of maintenance is being neglected and how they compare in quality of maintenance to other counties within their own district and throughout the state.

The same bar charts are used by operations and maintenance engineers at both the district and central office levels to better understand the quality of maintenance being attained in the various counties and as a tool to improve their direction and control of available maintenance resources.

In 1970, because of the interest within the Ohio Department of Transportation to improve the management of maintenance, a consulting firm was engaged to develop a method of measuring the quality of maintenance. The firm of Byrd, Tallamy, MacDonald and Lewis carried out the analysis of field data and developed the method now in use to measure the quality of maintenance. This consulting firm had earlier made a study of highway maintenance needs in Ohio that the department found useful. The

Publication of this paper sponsored by Committee on Maintenance and Operations Systems.

firm was thus already familiar with the current maintenance management policies and accounting methods. In developing the new method the firm proposed that the collection of raw data be made by the department's maintenance and traffic field engineers. By this means available funds for development were conserved so that the consultant's effort could be concentrated on the analysis of the field data and the development of the final method to be used.

During the early part of calendar year 1970 data were collected from 1,000 miles of highway in each of three transportation districts. Using the data from 3,000 miles of highway, Byrd, Tallamy, MacDonald and Lewis devised the present method of measuring the quality of maintenance on Ohio's highways.

The broad objectives of the maintenance quality survey are (a) to measure objectively the quality of maintenance achieved by county maintenance forces; (b) to establish, after sufficient experience has been attained, acceptable standards of maintenance quality within each district; and (c) to provide a means of setting annual district and statewide maintenance performance objectives.

DEVELOPMENT OF METHOD OF MEASURING MAINTENANCE QUALITY

The Ohio Department of Transportation specified that the measuring system developed by the consultant meet the following requirements:

1. The method should utilize a sample of the highway system in order to keep the field inspection work to a minimum;
2. The method was to be based on objective, quantitative measurements of physical conditions that could be easily and quickly recognized by engineering technicians and understood by maintenance personnel; and
3. The results of the field measurements were to be such that they could be presented in a simple, straightforward, easily understood manner.

The consultant recognized that the quality of highway maintenance affects both the physical integrity and the operational characteristics of the highway. Further, the operational characteristics or influences on the user can be divided into three areas: safety, rideability, and aesthetics. The method used for evaluating highway maintenance must accommodate all 4 areas of influence. Each of the numerous maintenance activities performed by the maintenance forces has a varying impact on the 4 areas of influence. It was both impractical and unwarranted to attempt to evaluate separately each maintenance activity. To determine their relative importance, the various maintenance activities were divided into 9 activity groups, which are given in Table 1 with the percentage of expenditure for each group.

The maintenance quality surveys do not include any measurement of the performance achieved in snow and ice control. Beyond that, the activity groups finally selected for the maintenance quality survey include most of the maintenance elements of an Ohio highway.

The system for measuring highway maintenance quality is not intended to be a system of taking an inventory of all maintenance work items on the highways. Routine inspection, location of work items, and work scheduling activities are a regular part of the duties of county superintendents, their foremen, and district general superintendents and other members of the district maintenance staff. The maintenance quality measurements were designed for making statewide quarterly surveys by special teams using a random sample to obtain representative measurements of the quality of maintenance being achieved.

The consultant found numerous references in the literature for maintenance quality measures and the parameters within which such measuring systems should be developed. The major points emphasized include the following:

1. The evaluation and inspection should be objective.
2. The human element of opinion or judgment should be eliminated and a quantitative value obtained wherever possible.
3. The inspection procedure should be standardized to ensure uniform reports for all areas of the state.
4. The measurement should not include the influence of faulty construction or poor design.

Table 1. Distribution of Ohio maintenance expenditures.

Activity Group	Percent of Expenditure (FY 1969)
Snow and ice control	24
Pavement maintenance	24
Vegetation control	12
Shoulder maintenance	11
Appurtenance maintenance	10
Drainage maintenance	8
Rest area maintenance	4
Bridge maintenance	4
Roadside litter removal	1
All other	2

Table 2. Summary of recordable conditions.

Condition	Description	One Unit Count for Each	Observation Scope
Pavement			
Surface			
Deterioration	2 in. depth and 24 $in.^2$ area	2 yd^2	All pavement
Obstructions	Obstruction or 6 in..diameter hole	Location	All pavement
Flushing	Area 1 yd^2 or more	100 lineal ft	All pavement
Striping			
Deterioration	Stripe missing, 6 lineal ft or more	1/10 mile	All pavement
Auxiliary marking			
Deterioration	Markings do not delineate	Location	All pavement
Shoulders			
Surface			
Drop-off	2 in. depth and over 6 lineal ft	100 lineal ft	One shoulder
Obstructions	Obstruction or hole, 2 in. deep, 12 in. diameter	Location	One shoulder
Appurtenances			
Guardrail			
Appearance	Rusty, needs painting	100 lineal ft	All guardrail
Deterioration	Rotten posts, bent rail	100 lineal ft	6 runs of rail
Signing			
Deterioration	Nonfunctional sign	Sign	All signs
Roadway			
Vegetation			
Appearance	Deviation from mowing policy	1/5 mile	All medians and roadsides
Litter			
Appearance	Count of 10 or more items of litter	1/10 mile	All medians and roadsides
Drainage			
Ditches			
Obstruction	Obstruction over 50 percent	100 lineal ft	All ditches
Culverts[a] and pipes			
Deterioration	Repair required	2 yd^2	6 structures
Obstruction	Obstruction over 50 percent	Structure	6 structures

[a]Culverts are defined as pipes or structures with a clear span of less than 10 ft.

5. The evaluation of the condition should be done the same way under any weather conditions.
6. The evaluation of the measurements should provide a basis for comparing the quality of maintenance in various department subdivisions.
7. The various maintenance activities should be weighted to reflect their relative impact on the total highway facility.

The American Association of State Highway and Transportation Officials has defined the objectives of highway maintenance and traffic services in the Manual of Uniform Highway Accounting and Financial Management Procedures. The AASHTO definitions make it clear that AASHTO is concerned with the condition of the elements of a highway. Therefore, the ultimate measure of highway maintenance quality should relate to the condition of the highway elements. Likewise, the AASHTO definition of traffic services indicates that the quality of traffic service should be a measure of the safe, convenient, and economical transportation provided to the public.

The measures and procedures developed were structured to reflect maintenance quality within the AASHTO concepts. Therefore, quality of maintenance may be defined as a measurement of the degree of accomplishment of the maintenance objectives as defined by AASHTO.

The quality of pavement maintenance, for example, is a measurement of how well the pavement is kept in its as-built condition and how well it provides safe, convenient, and economical highway transportation. Perfection in maintenance quality becomes realistic for obvious economic reasons. No highway organization can afford to maintain its system in an essentially new condition. Rather, a gradual deterioration of the elements is accepted and, at intervals, reconstruction is programmed. Because evidence of such deterioration does exist, it can be measured quantitatively and the resulting values can be used to reflect the quality of maintenance accomplished on the highway system.

At intervals, the various elements of the highway facility can be examined and their condition measured. Assuming that the element is maintainable, a good condition will reflect no deterioration or a high level of maintenance quality. A poor condition will reflect a low level of maintenance quality. Therefore, measurements of the condition of the various elements of a highway system become measurements of the quality of the maintenance being realized on the highway system. This measurement of the quality of maintenance provides an additional means of control for maintenance managers.

MEASUREMENTS

Since maintenance quality can be evaluated in terms of the condition of various elements of the highway, these elements, along with their measurable characteristics, need to be identified. The approach taken by the consultant was to identify those characteristics that indicate deterioration of the physical integrity or a reduction in the operational characteristics of the highway.

Because a sampling procedure was to be used, it was important to select identifiable conditions that occurred with reasonable frequency. A series of highway conditions referred to as "recordable conditions" were selected and defined as specific conditions to be observed on the highway system. The Recordable Condition Survey called for unit counts to be made of the elements and conditions given in Table 2.

From the table it is seen that one unit of pavement surface deterioration consists of an area of over 24 in.^{2} and under 2 yd^2 of pavement where the deterioration is 2 in. or more in depth. The entire pavement area in the 2-mile sample section is inspected to determine the number of recordable conditions of this type.

One unit of shoulder drop-off consists of more than 6 lineal ft and less than 100 lineal ft of drop-off that is 2 in. or more in depth. For this type of recordable condition only one shoulder of the road is observed over the length of the sample section.

The survey of maintenance quality does not include bridges. Because an annual detailed inspection is made of every bridge on the state highway system, an evaluation of bridge maintenance is not included in the method described herein. The bridge inspection system now used is considered adequate to provide information relating to the condition of structures of over 10 ft clear span.

SURVEY METHOD USED TO MEASURE MAINTENANCE QUALITY

The recordable conditions given in Table 2 were used on the first survey, which was begun in the spring of 1971 and completed in November of that year. A single 2-man survey crew was used in the beginning, and the first 2 surveys, which were made on randomly selected statewide sections, each required 6 months to complete. In July of 1972 it was decided that maintenance quality surveys should be made quarterly. To increase the survey frequency, a second survey crew was added.

Approximately 1,650 sections of the highway are inspected on each statewide survey. The sections are each 2 miles in length, which means that approximately 19 percent of the total centerline mileage is covered by each survey. The sections are randomly selected by computer from the road inventory. This inventory consists of the straight-line diagram sections and is on file in the Ohio Department of Transportation Computer Center. Because some sections of the inventory are less than 2 centerline miles in length, they are not used in selecting survey sections. Sections that are over 2 miles in length are divided into 2-mile sections, and these 2-mile sections are included in the pool from which sections are chosen. After dividing the longer sections into 2-mile sections, the remaining or last section is over 2 miles and less than 4 miles in length. The total number of sections in the population established in this manner is 4,540.

The Ohio State Highway system is classified into 5 route types: Interstate, major thoroughfare divided, 2-lane major thoroughfare, auxiliary, and local highways. Five sections are chosen at random in each of 88 counties from each of the 5 route types. If 5 sections were available in each of 5 route types in each of the 88 counties, a total of 2,200 sections would result. Because there are many counties without any Interstate route mileage and because of a lack of sufficient sections in the population because of short sections, the sample surveyed consists of 1,650 sections rather than 2,200. However, the number of sections surveyed constitutes a relatively large sample.

The survey crews use the following procedure in carrying out their work:

1. For each of the 12 districts, the county, route number, and mileage log point of each section to be inspected are listed.
2. A map of each district is marked to show the location of each highway section to be inspected. The map is used to make up daily itineraries for the survey work.
3. Inspections are made of each section and a Recordable Condition Report (Figure 1) is completed. These reports are forwarded to the Central Office Bureau of Maintenance for processing.
4. In addition to inspection of the randomly selected sections of highway, the survey crews inspect one-half of the highway rest areas in each county on each survey.

DATA REDUCTION AND BAR CHART PLOTTING

The field data shown in Figure 1 are converted to the number of recordable conditions per centerline mile for each route type. The resulting values for each county and maintenance work category are then weighted by the number of lane-miles in each route type. The resulting values are then listed on computer code sheets and processed as input for the Calcomp Plotter. The weighted values of recordable conditions per mile are plotted in bar chart form (Figure 2) by the Calcomp Plotter. One of the features of the plotter is the automatic selection of the vertical scale so that the resulting plot fills the chart area.

The second item shown on the bar chart plots is the cost per lane-mile for the particular maintenance activity shown. The values of cost shown are the direct expenditures by Division of Highways personnel for labor, equipment, and material reported routinely each day by each county and processed by the Bureau of Auditing and the Computer Center. Some plots are made to show total direct cost per lane-mile (labor, equipment, material) and other plots are made to show labor expenditure per lane-mile only. The reason for using labor expenditure only in some charts has been to make available such charts in a shorter time than that required to produce charts with total cost per lane-mile. The ideal chart would show total cost per lane-mile for the 3 months immediately preceding the completion of the maintenance quality survey.

Figure 1.

STATE OF OHIO — RECORDABLE CONDTION REPORT — DEPARTMENT OF TRANSPORTATION

ROUTE SR 554 COUNTY Gallia DATE 7-31-73
SECTION NO. 6B OBSERVERS Hughes & Stewart

CONDITION	ONE UNIT COUNT FOR EACH	UNITS	TOTAL
PAVEMENT			
Surface			
Deterioration	2 Sq. Yd.	~~||||~~ ||||	9
Obstruction	Location			1
Flushing	100 Lin.Ft.	|||	3
Striping			
Deterioration	1/10 mile	~~||||~~ ~~||||~~	10
Auxiliary Marking			
Deterioration	Location		
SHOULDERS (Surface)			
Drop-Off	100 Lin.Ft.	~~||||~~ ~~||||~~ ||	12
Obstruction	Location	||||	4
APPURTENANCES			
Guardrail			
Appearance	100 Lin.Ft.		
Deterioration	100 Lin.Ft.		
Signing			
Deterioration	Sign		
ROADWAY (Appearance)			
Vegetation	1/5 mile	~~||||~~ ||	7
Litter	1/10 mile	||||	4
DRAINAGE (Obstruction)			
Ditches	100 Lin.Ft.		
Structures	Structure		
STRUCTURES			
Deterioration	2 Sq. Yd.		

ODOMETER LOG
Control Point 2.76 (Br 2.25) (Pave Narrows)
Section Start 0.00
Guardrail (end of 5th run) ~~||||~~ | — 1.05 .58 .66 .79 1.01
Drainage (6th structure) ~~||||~~ | — 1.59 .30 .56 .71 .88 1.43
Section end 4.76
Length of Section 2 miles

Figure 2.

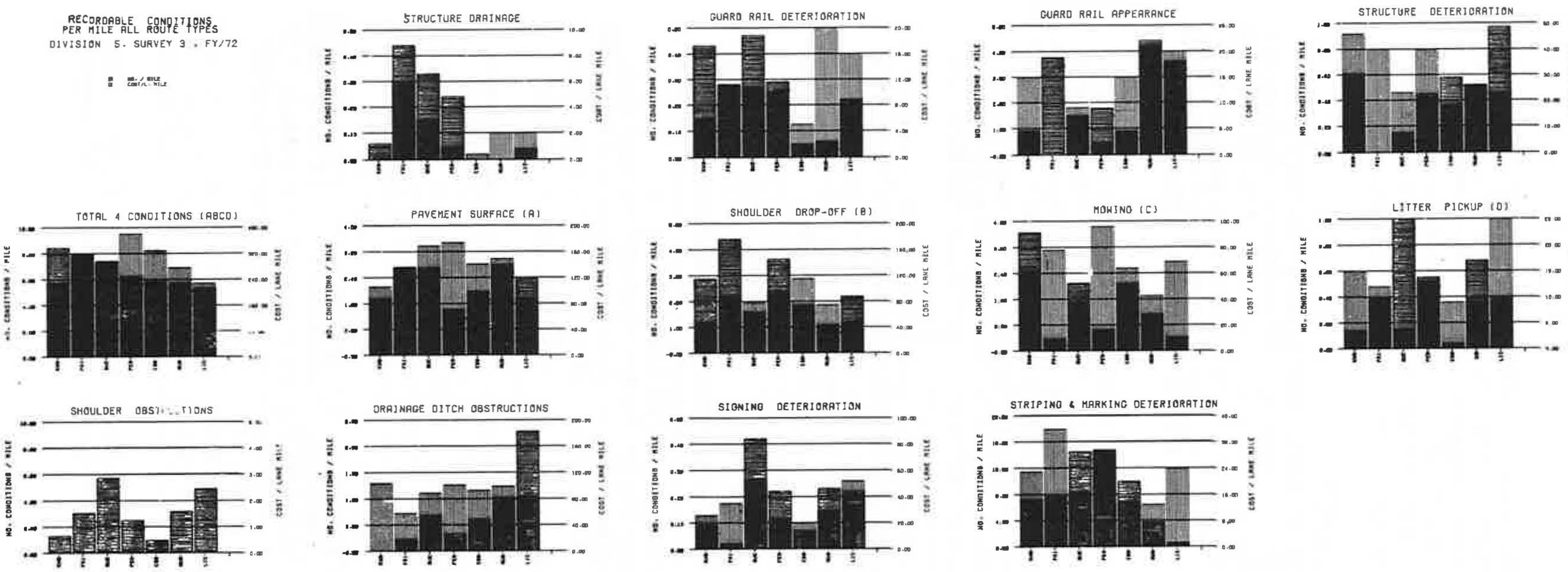
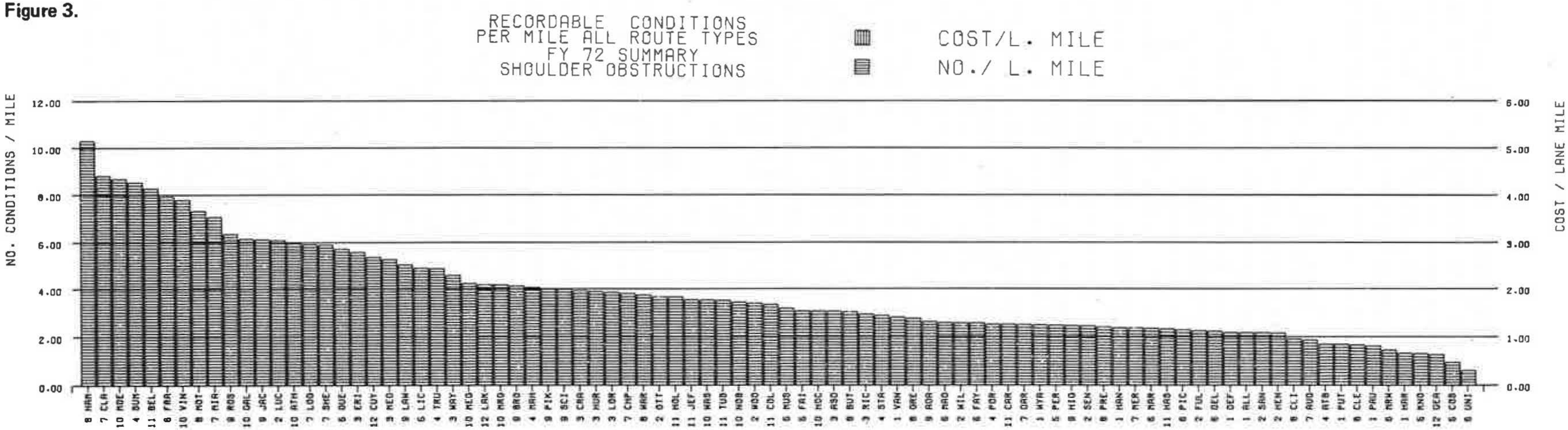


Figure 3.



Beginning with fiscal year 1973, plots were made showing the average values of recordable conditions per mile for all surveys made during the fiscal year. The total direct costs per mile for the fiscal year were shown with the number of recordable conditions per mile. The plots for each successive year will be compared both for recordable conditions and for expenditures per lane-mile to compare annual maintenance performance as represented by the average of 4 quarterly surveys.

Bar Charts of Quality and Cost of Maintenance

The recordable condition data are presented in several forms of bar charts. In actual practice the number of recordable conditions per mile is plotted in black ink and the cost per lane-mile for the same county is plotted in red ink over the black bar. The 2-color bar charts are much more graphic and are more easily understood than the black-and-white bar charts shown here. The 3 letters that appear at the bottom of each bar are the abbreviation for the county for which the data are plotted. The following four types of bar charts are in current use:

1. District bar charts for individual field surveys—These charts show the number of recordable conditions per mile as determined in a particular survey for 13 maintenance categories and a fourteenth chart that is a plot of the sum of the recordable conditions for pavement deterioration, shoulder drop-off, mowing, and litter pickup. The cost per lane-mile values on this chart are the expenditures for direct labor for the calendar quarter preceding the date of the survey. The bar charts are presented on one 11 × 28-in. page similar to that shown in Figure 2. (Figure 2 does not show a bar chart for rest areas, which is included in current versions.)
2. District bar charts for the fiscal year period—These charts are the same type of chart as described above except that the recordable conditions shown are the average values of all surveys made during the fiscal year. The cost per lane-mile values on this chart are the fiscal year total expenditures for labor, equipment, and material.
3. 88-county bar charts for individual maintenance categories—These charts show the same recordable condition and cost values referred to in No. 2 above with values plotted for all of the 88 counties in the state. Each chart is for an individual maintenance category. Figure 3 shows this type of bar chart. The 3-letter abbreviation for the counties and the number of the district that contains the individual county is shown below each bar. In Figure 3 only recordable conditions per mile are shown. In most such charts the cost is also shown as a red bar printed over the black bar.
4. County history charts—These charts (Figure 4) show the recordable conditions per mile and the costs per lane-mile on successive surveys in a particular county. The numbers shown below each bar indicate the particular survey that the bar represents.

The following paragraphs give details concerning the bar charts for the various maintenance activities included in the maintenance quality survey.

Pavement Surface—The pavement surface maintenance quality measurement shown in Figure 5 is the sum of the recordable conditions per mile (Table 2) for pavement deterioration, pavement obstruction, and pavement flushing. The expenditures per lane-mile shown are for (a) surface patching; (b) full-depth pavement replacement, including repair of blowups; (c) filling and sealing cracks and joints; (d) surface treatment, sealing, deslicking, and screening bleeding pavements; and (e) pavement jacking.

Mowing, Litter Pickup, Guardrail Deterioration, Sign Deterioration, Culvert Drainage, Structure Deterioration, Drainage Ditch Obstruction—Each of these 7 activities is plotted singly from the field measurements of recordable conditions as defined in Table 2. The cost per lane-mile that is plotted is the expenditure for each of these individual activities as routinely reported by the county timekeeper.

Shoulder Drop-Off—The definition for a recordable condition in this category is given in Table 2. Expenditures per lane-mile for grading or adding material to shoulders and for widening, reshaping, or stabilizing short sections (less than 500 ft) are also shown in the bar chart.

Total 4 Conditions—This chart (Figure 6) combines the data of 4 other charts to provide a composite rating of individual county maintenance performance. The 4 categories

Figure 4.

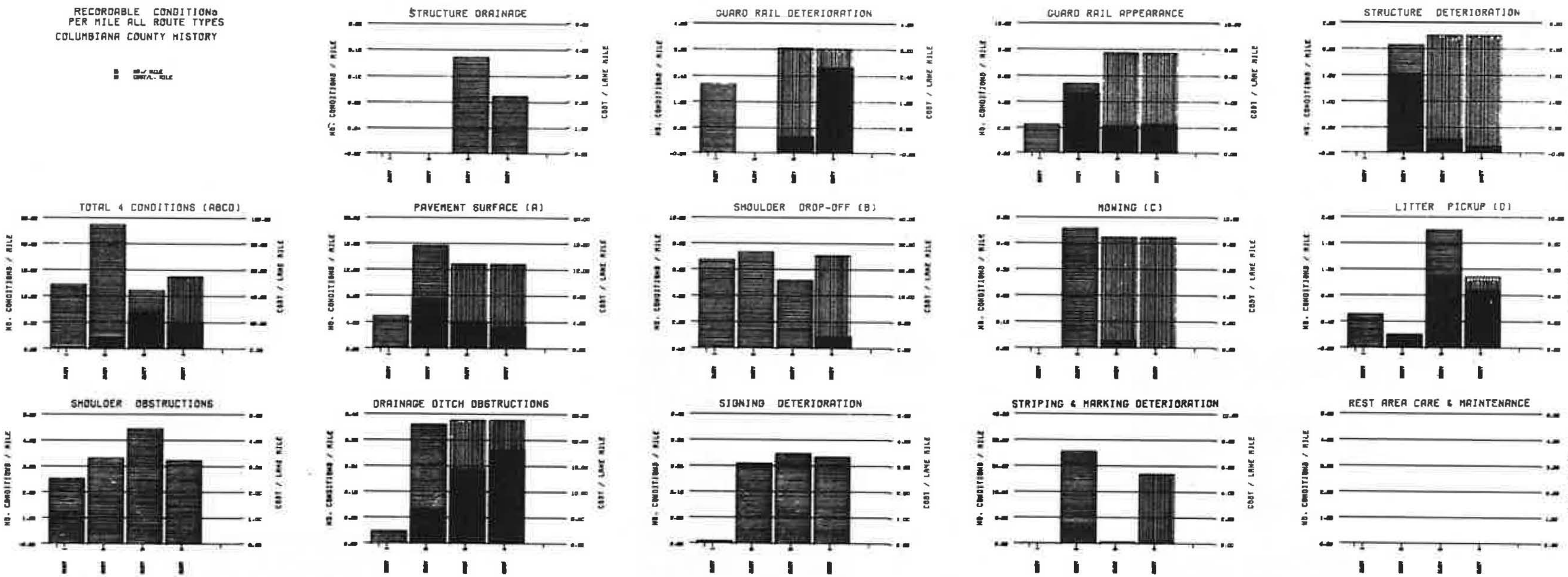

RECORDABLE CONDITIONS
PER MILE ALL ROUTE TYPES
COLUMBIANA COUNTY HISTORY
STRUCTURE DRAINAGE
GUARD RAIL DETERIORATION
GUARD RAIL APPEARANCE
STRUCTURE DETERIORATION
TOTAL 4 CONDITIONS (ABCD)
PAVEMENT SURFACE (A)
SHOULDER DROP-OFF (B)
MOWING (C)
LITTER PICKUP (D)
SHOULDER OBSTRUCTIONS
DRAINAGE DITCH OBSTRUCTIONS
SIGNING DETERIORATION
STRIPING & MARKING DETERIORATION
REST AREA CARE & MAINTENANCE
NO. CONDITIONS / MILE
COST / LANE MILE

Figure 5.

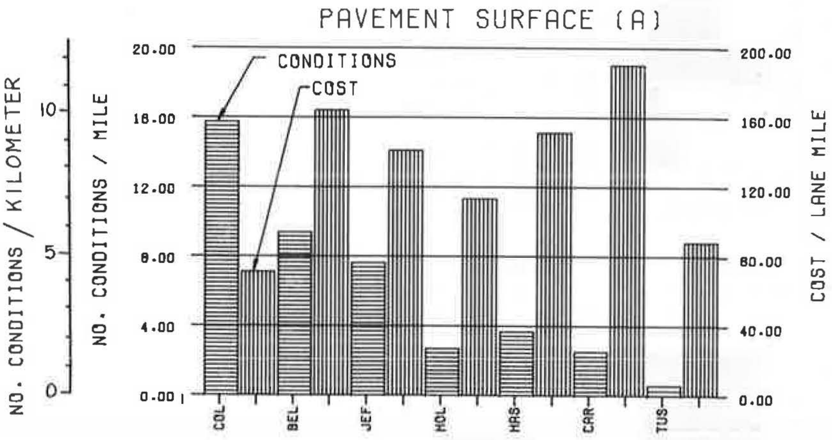


Figure 6.

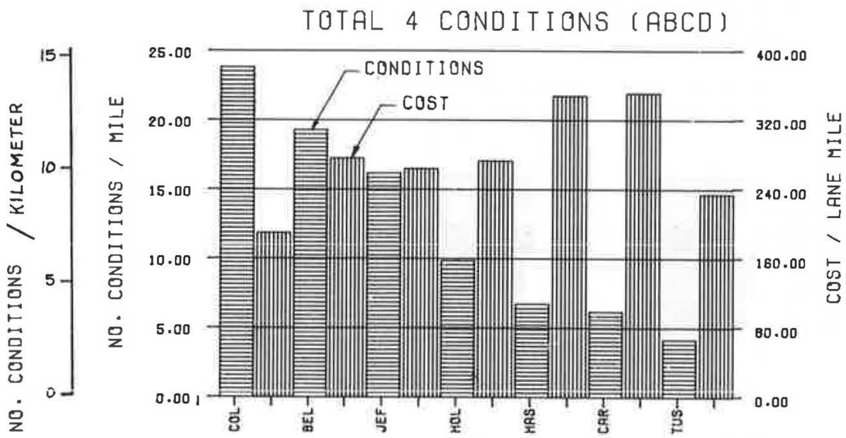
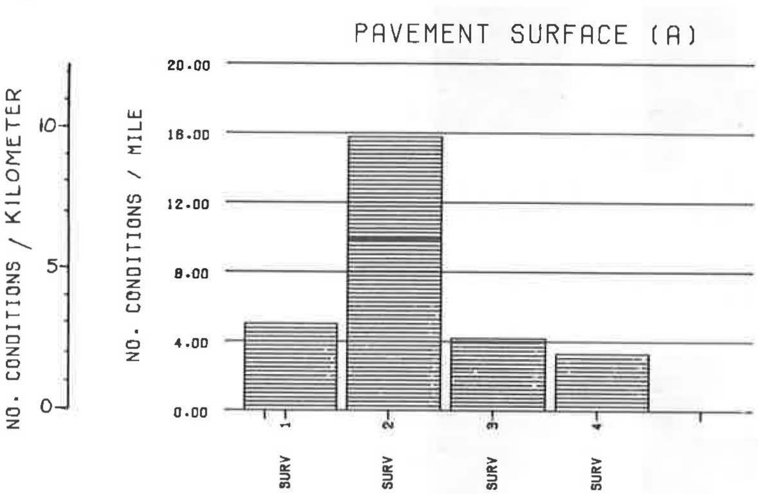


Figure 7.



that are combined were chosen because the recordable conditions in these categories are the result of work by county forces only whereas in other categories district crews contribute to the maintenance work either exclusively or in combination with county maintenance forces.

Category	Item	Weighting Factor
Pavement surface	(A)	1.6
Shoulder drop-off	(B)	1.4
Mowing	(C)	0.6
Litter pickup	(D)	0.4

Because both safety and comfort are involved in items A and B, whereas they are not involved or are involved to only a minor degree in items C and D, the values in the 4 categories are weighted to reflect their relative importance to the highway user. The weighting factors used are given opposite each item. The bar chart for Total 4 Conditions (ABCD) is plotted with the county having the greatest number of recordable conditions first, and the remaining counties are plotted in the order of decreasing values of number of recordable conditions. The same order for the individual counties is used in all other bar charts. This order of plotting is a constraint of the plotter program. Although the bar charts of Figures 5, 6, and 7 are shown here as separate plots, in practice they are all plotted on one large sheet (Figure 2) by the Calcomp Plotter. The plot of cost per lane-mile is an overplot in red ink.

Guardrail Appearance—The recordable conditions per mile used for this item are in accordance with the definition in Table 2. The cost per lane-mile used in this case is the annual contract cost of painting guardrail in each individual county. The recordable conditions shown result from improper programming of contract painting by the district. Such painting is done on a regular 4-year cycle, and this frequency of painting has been found to be adequate.

Shoulder Obstructions—The recordable conditions per mile for this item are as defined in Table 2. At present no cost per lane-mile is shown in the bar chart for this type of work.

Striping and Marking Deterioration—The sum of the recordable conditions per mile (Table 2) for striping deterioration and auxiliary marking deterioration is shown in this bar chart. The expenditures per lane-mile shown are for (a) auxiliary markings, (b) spot and tee markings, (c) other special markings, (d) centerline marking, (e) edgeline marking, and (f) lane line markings.

Rest Area Care and Maintenance—Half of the total rest areas in each county are inspected on each quarterly survey by the maintenance quality survey crew. Figure 8 shows the form used by the survey crew in evaluating rest area maintenance. Definitions are not included in Table 2 for items on this inspection form. Each item has a listed rating value and the total value of all items on the check sheet is 100. The value for a given rest area is the difference between 100 and the total on the inspection sheet. Because Ohio rest areas are of various configurations, depending on the date of construction and the highway facility served, a method of weighting was used to determine the value of recordable conditions per mile plotted for each county. The ratings for each rest area are weighted in accordance with the following weighting factors and the weighted values are plotted on a rest area bar chart:

Class of Rest Area	Weighting Factor
Interstate highway	1.67
Primary highway	1.00
Secondary highway	0.33

Analysis of Bar Charts

Analysis of 2 bar charts is included here to illustrate the use of the maintenance quality survey and bar charts.

Figure 8.

REST AREA INSPECTION FOR MAINTENANCE QUALITY PERFORMANCE SURVEY

#________ ROUTE________ COUNTY________ REPORT BY________

ITEMS TO RATE	REQUIRED MAINTENANCE	WT.	MAX. VALUE	RATINGS AND DATE				
SANITATION	Odoriferous	10	27					
	Dirty	10						
	Lacks Supplies	3						
	Writing on Walls	3						
	Storage Area Cluttered	1						
FACILITIES	Structural Repair	2 Ea.	24					
Toilet, Well Shelter,	Staining or Painting							
Picnic Shelter, Motorist	Concrete Repair							
Service, Bulletin Boards,	Repair Vandalism							
Grills, Picnic Tables	Utility Repair							
GROUNDS	Littered	5 Ea.	20					
	Improve Lawn Care							
	Improve Plant Care							
	Remove Dead Trees							
PARKING AREA & RAMPS	Surface Deterioration	3 Ea.	15					
	Littered or Oil Spots							
	Drain Obstruction							
	Parking Lines Faded							
	Ruts Along Ramps							
MISCELLANEOUS	Sweep/Remove Snow	1 Ea.	14					
Walks, Guard Rail, Signs,	Repair							
Telephone, Fence, Light	Replace							
Posts, Delineator Posts	Info. on Bull. Board							
Caretaker	Appearance							
	Attention to Duty							
	REST AREA RATING		%					

Indicate which maintenance items are required and the exact location by a circle. 2/9/73

Total 4 Conditions (ABCD)—It can be seen from Figure 6 that the county with the fewest recordable conditions is TUS and the county with the most recordable conditions is COL. This chart has the counties plotted in the order of decreasing values of the number of recordable conditions. The cost per lane-mile as shown by this chart indicates that, in general, the counties having the higher expenditures have fewer recordable conditions.

Pavement Surface—In Figure 5 the county (COL) with the lowest expenditures per lane-mile has the greatest number of recordable conditions per mile. Comparing the counties of COL and TUS, it is seen that expenditures per lane-mile are approximately the same, yet COL has the greatest number of recordable conditions and TUS has the fewest. The bar chart for pavement surface recordable conditions showing all of the 88 counties in Ohio (not included here) indicates that COL county has the second highest number of recordable conditions in the entire state whereas TUS county is within the lowest 11 counties of the state. Figure 7 shows the recordable conditions per mile for COL county on 4 successive surveys. The number of pavement surface recordable conditions was sharply reduced in COL county as shown by the third and fourth surveys. Similar analyses can be made of the other maintenance categories. The use of the charts and the interpretation of the values shown by the several types of bar charts will vary depending on whether the study is made at the county level, the district level, or the central office management level.

USE OF MAINTENANCE QUALITY SURVEY MEASUREMENTS

The central managements in the Division of Highways and the State Department of Administrative Services are concerned primarily with statewide maintenance performance and the overall quality of maintenance. Based on this viewpoint and the data from 9 statewide surveys taken during 3 fiscal years, management will use the surveys to study statewide average values of recordable conditions per mile for each maintenance category. From the average values of all of the surveys made during a given fiscal year, the quality of maintenance can be compared from one year to the next. A statewide objective has been established to equal or better the previous annual statewide average of recordable conditions in each maintenance category. Two surveys were made during fiscal year 1972, 3 surveys were made in fiscal 1973, and 4 surveys will be completed in fiscal 1974 and in each year thereafter. It is believed that the average of 4 surveys made in 1 year will provide a sound basis for evaluating the quality of maintenance for a given year. Because the method was in the development stage in fiscal 1972, a comparison between fiscal 1972 and fiscal 1973 was considered to be of relatively small importance. All levels of management are looking forward to a comparison of fiscal 1973 and fiscal 1974 to determine if the statewide objective of reducing the number of recordable conditions in each category has been met.

At the district level the charts are used in the following ways:

1. In some districts the district deputy director uses the bar charts as a source of information with regard to the quality of maintenance in the several counties within his jurisdiction. When a county is noted to have a higher number of recordable conditions per mile than the district average, the district deputy director may request that corrective measures be taken or ask the district operations engineer for an explanation of the poor quality.
2. The 88-county bar charts (Figure 3) are used by district maintenance managers for comparing the quality of maintenance in their district with the quality in other districts. Although the central office management does not call attention to differences in the quality of maintenance between districts, it is only natural that district managers compare their quality measurement rating with the values of other districts. The 88-county bar chart may show that a county that appears either extremely good or extremely poor in a district comparison has an average quality rating when compared to all other counties in the state. The district operations engineers also like to compare the position of their counties with all of the 88 counties from one year to the next. Dramatic changes in maintenance quality can sometimes be caused by a change in the county maintenance superintendent. Both the 88-county and the district bar charts have been found useful in confirming inadequate county supervision.

3. The district bar charts are used by district operations and maintenance engineers as a source of information in comparing the quality of maintenance between counties under their supervision in specific work categories. One county maintenance superintendent may excel at shoulder maintenance and neglect ditch drainage. A study of the district bar charts can be helpful to the district operations engineer in planning corrective measures where needed. Such measures consist of helping a county superintendent to plan his work better or in acquainting him with a better method of doing a certain maintenance job.

4. In one district the bar charts are used to give recognition to the county superintendent whose county has the fewest recordable conditions. Although the surveys are made quarterly, the survey made at the end of the calendar year is used to determine the county with the highest quality of maintenance. For this purpose the Total 4 Condition values shown in Figure 6 are used. Reports from the district using the measurements of maintenance quality in this way indicate the development of a highly desirable competitive spirit among the counties of the district.

5. A common use of the district bar charts in the district maintenance offices is as a basis for discussion of maintenance quality between the county superintendents and their supervisor, the district maintenance engineer. Because the measurements are made by a central office survey team, the third-party concept makes the discussion between supervisor and subordinate more objective and less personal in nature.

CONCLUSION

Measuring the quality of maintenance that exists on a highway system at a particular time provides useful information to all levels of maintenance management. To our knowledge, such information has not previously been available in quantitative terms. Ohio has used the method reported here over a 3-year trial period, during which implementation of the basic method has been expanded. The survey results are transmitted to all levels of management on a timely basis through the use of 4 different types of bar charts plotted by computer in 2 colors.

Although survey results are plotted in bar chart form for each individual survey, it is believed that the best interpretation of the quality of maintenance is obtained by averaging the results of 4 quarterly surveys to provide a measure of the quality of maintenance for a 12-month period.

The method used to measure the quality of maintenance is objective and has gained the acceptance of the maintenance engineers in the 12 field districts of the Ohio Department of Transportation.

Standards of maintenance quality can be established by the use of the Ohio method after sufficient data have been accumulated. Although tentative standards were set in Ohio after making 5 surveys during a 2-year period, such standards will be confirmed at the end of fiscal year 1974, at which time data from a total of 9 surveys will be available. The method described here is recommended for use by other states. Each state should develop its own standards of the quality of maintenance based on data from surveys in its own state.

TRAINING OF MAINTENANCE PERSONNEL

Ray J. Wilson and Travis Smith, Division of Highways,
California Department of Transportation

In California the complexities of administering the expanding highway maintenance function created a need for additional and more comprehensive training of both management and line personnel. A task-force approach was utilized to determine current and future training needs of highway foremen, landscape foremen, and superintendents. Traditional approaches of lectures and short courses were discarded, and live-in academy methods using realistic settings and training material were adopted for maintenance supervisors. Gathering many and varied supervisors in the academies identified additional training needs. Supervisors must be trained to become people managers if they are to become efficient maintenance managers. This need is being met by a basic maintenance supervision course that is now being implemented. To supplement on-the-job training, various correspondence courses have been developed. They are presently being taken by 2,700 road and landscape employees; another 400 employees have completed the courses. California's goal of reducing maintenance costs is being met by increasing employees' knowledge and understanding of maintenance operations.

•A FEW years back, the California Department of Transportation took a long, hard look at its maintenance operations. We found increasing complexities and problems in meeting work load requirements within budgetary limitations.

Consider, for example, the growth of the job brought about by more lane-miles, more structures, and more landscaped areas. Although improved technology allows some of the work to be done faster, the unit cost of labor and materials is rising and the number of dollars available is not growing as fast as the job. Heavier traffic volumes make maintenance more difficult and time-consuming. In addition, the public wants higher maintenance standards, more consideration to aesthetics, environment, and ecology, and more snow-country lane-miles kept open all winter.

Protection of the huge investment in the California highway system requires a vigorous maintenance program and organization. To provide such a program, the state is divided into 11 transportation districts. Each of the districts has a self-contained maintenance staff as well as staffs for other functions such as planning, design, right-of-way, construction, and traffic.

Staff responsibility for maintenance is vested in the district chief of operations and the district chief of maintenance. The chief of maintenance in turn supervises the district office functions and the various field superintendents, who are strategically located throughout the district. Each field superintendent is responsible for the supervision and direction of effort of a number of field crews, depending on the quantity of inventory to be maintained and geographical area covered.

The average field superintendent in the state is responsible for maintaining approximately 215 centerline miles and supervises about 55 general maintenance employees. The average foreman maintains approximately 48 centerline miles with a 6-man crew. Generally, landscape foremen and their crews are assigned to superintendents and are responsible for maintaining landscaped areas. Each district has a special crews superintendent who, with foremen and crews, is responsible for maintaining specialty items such as pavement delineation, signs, signals, lighting, tunnels

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and tubes, ferry and drawbridge operation, and bridge repair. At present there are 81 superintendents' territories and 515 crews, generally supervised by foremen. In Sacramento, the headquarters maintenance branch provides functional guidance and responsibility for district operations on a statewide basis.

In a few cases, highway superintendents in metropolitan districts are supervising more maintenance people than there were in a small rural district's entire maintenance department not many years ago. With the expansion of maintenance departments to handle the work load created by accelerated highway construction, including the Interstate program, and new concepts of highway beautification in the form of extensive highway landscaping projects, the opportunities for advancement in the maintenance field are greater than in previous times. Superintendents and some foremen have grown up with the expanded program. However, the fact remains that maintenance people are now advancing with fewer years of service and with less opportunity to become exposed to the many problems of a supervisor.

This places an increasing burden on maintenance forces, particularly on superintendents and foremen. It appeared that additional training of these supervisors was necessary to meet current problems and to cope with anticipated future conditions.

To see if training really was required, and what kind, an extensive study of superintendent and foremen jobs was conducted with the following objectives in mind:

1. Determine current problems;
2. Get a better inventory of the skills and knowledges of the incumbents; and
3. See what skills and knowledges newly appointed people to those positions should have.

The study included the following information-gathering activities:

1. Discussions with the individuals who perform regular staff reviews of the function;
2. Interviews with working, supervisory, and management levels to identify problem areas;
3. Detailed observation of maintenance people at work to see specifically what they do and what gives them problems;
4. Consultation with higher level supervisors and others who have contact with maintenance forces; and
5. Analysis of cost reports and budget submittals.

The information gathered was carefully reviewed by a task force of selected maintenance supervisors. The conclusion was that training was needed, both to meet future demands and because prior training of the superintendents and foremen had not covered several important aspects of the job.

The task force assigned priorities to the identified needs. We decided that 1 week of intensive training for all of the approximately 700 superintendents, landscape specialists, and foremen would make a significant contribution toward solving the problem.

The needs identified as most pressing were as follows:

1. Decision-making skills in handling both ordinary maintenance administration and disaster operations;
2. Skill in preparing annual budgets and in using cost reports as management tools;
3. Skills in estimating the cost of repairs;
4. Familiarity with new maintenance techniques and tools;
5. Public-contact skills, including those needed in relationships with other agencies;
6. Skills in coping with personnel problems in hiring, firing, disciplining, and motivating; and
7. Knowledge of landscape maintenance, because superintendents have recently acquired supervision of this expanding function.

These were required for the general foreman and superintendents. The needs of the landscape foreman group are slightly different and it was decided to have separate training for these supervisors.

HIGHWAY MAINTENANCE ACADEMY

The objective was to have the superintendents and foremen learn the application of skills to their jobs. It was therefore decided that the traditional lecture, short-course approach to this training would be inefficient. The methods that were adopted for the live-in highway maintenance adademy are as follows:

1. Before attending the academy, the student completes a pre-academy, self-study course. This consists of 260 pages covering personnel, public relations, service and supply, budgets, estimating mathematics refresher, landscaping, outdoor advertising, and permits. The student retains this material for future use, but the primary goal is to give him the knowledge and background information necessary to gain full benefit from the academy work.
2. At the academy the superintendents and foremen practice the skills required in a setting as realistic as possible. They receive immediate feedback as to how well they do, then are given furuther opportunities to practice to improve their skills.
3. Because these methods work best in small groups, the 35 trainees are divided into 7 teams of 5 men each. Throughout the academy these teams compete against each other. Points are assigned for each problem completed and for how well it is solved. At the end of each day points for each team are displayed. Each team's total points are accumulated, and at the end the members of the winning team each receive a new hard hat with a "winning team" decal and a gold seal on their certificates of completion. This element of competition adds a great deal to the students' interest and motivation.
4. To give a framework in which this training could operate, an artificial transportation district was created on paper within the existing highway structure. Staffing charts, budgets, equipment lists, telephone books, maps, and other documents were prepared for use by the teams. All problems at the academy take place within one superintendent's territory in the mythical district.
5. During the instruction, a compressed version of the superintendent's work is simulated. Mail is delivered that requires replies. The telephone, manned on the other end by instructional staff, brings maintenance and personnel problems to the superintendent. Official visitors, again played by staff members, call at the superintendent's office. Thus, the trainees are required to sift and handle routine problems.
6. Closed-circuit TV is used as a training aid. A television camera is used to tape each team in action during various parts of the academy. Summaries of these tapes are played back for the teams to see and hear themselves and give their own evaluation of how well they did.

These methods are followed to a large degree throughout the academy. Because of this, the number of people who can be trained at any one academy session is quite limited. Teams of 5 seem to be a maximum, and 7 such teams is about all that can be satisfactorily handled at one time. These students are gathered from all 11 transportation districts. Each 5-man team has no more than 1 student from a given district.

Approximately 50 hours of classwork are covered during a highway maintenance academy. The cost of one academy, Monday through Friday, including board, lodging, and salaries for both students and instructors, is estimated at $18,000. Some 735 highway superintendents, foremen, and potential foremen have been trained in the 21 maintenance academies held since 1966. Two maintenance academies a year are now adequate to meet current needs for this training.

At each academy, the full-time instructional staff is composed of 4 senior superintendents and 3 highway superintendents. In addition, 15 specialists from various fields serve as part-time instructors when the academy subject matter is concerned with their specialty areas.

Headquarters maintenance branch operates the academy, providing the instructional material and several of the part-time instructors. The full-time staff is borrowed from the districts for each academy on a rotating basis. This has several benefits, including adding fresh ideas and attitudes to the academy training.

Figure 1 shows the subjects covered in a highway maintenance academy session.

Figure 1. Highways maintenance academy schedule.

MONDAY

- Academy Briefing
- Public Relations

TUESDAY

- Personnel Processes
- Personnel Panel - Open Discussion

WEDNESDAY

- Human Relations
- Maintenance Management System
- Other Agency Relationships
- Service and Supply
- Elements of Letter Writing

THURSDAY

- Safety
- Tort Liability
- Outdoor Advertising
- Materials and Research
- Equipment - Maintenance Relationships
- Landscape Management
- Comprehensive Examination
- Examination Review

FRIDAY

- Simulation
- Awards

Figure 2. Highways landscape academy schedule.

MONDAY

- Academy Briefing
- Nonchemical Means of Pest Control
- Question and Answer Period
- Equipment Discussion

TUESDAY

- Personnel Case Problems
- Personnel Case Problems Critique
- Human Relations

WEDNESDAY

- Maintenance Management System
- Parasites and Predators
- Safety

THURSDAY

- Public Relations
- Biological Control of Weed Pests
- Service and Supply Presentation

FRIDAY

- Landscape Architecture
- Torts
- Awards

HIGHWAY LANDSCAPE ACADEMY

The purpose and objectives of the landscape academy are the same as those outlined for the maintenance academy, with emphasis on the technical aspects, supervision, and administration of landscape work as performed in most districts throughout the state.

Seven landscape academies have been held since their beginning in 1967. Personnel who attend are landscape leadingmen, landscape foremen, highway tree foremen, and landscape specialists I.

Trainers are assigned from landscape specialist classes from both headquarters maintenance branch and the districts. Several other departments also furnish instruction during each session.

An objective of the Department of Transportation is to maintain both the landscape plantings and the natural growth on the roadsides as economically as possible with a minimum use of chemical pesticides. To implement the research work that has been accomplished and realize the benefits of this research, the training of the maintenance employees is accomplished by a series of illustrated lectures and demonstrations by the faculty of the University of California and by U.S. Department of Agriculture scientists.

As in the maintenance academy, there is a pre-reading unit consisting of 90 pages covering material on personnel, public relations, and technical landscape work.

Figure 2 shows the subject matter covered in a landscape academy.

There is no exact yardstick that can be used to measure educational courses of this type that will indicate direct benefits to the department or the individual. The feedback from ex-students, instructors, and district chiefs of maintenance indicates that considerable knowledge of administration, personnel problems, estimating, general policy, budgets, and cost reporting, to name a few, has been assimilated beneficially. Many of the students were made aware of the proper way to handle disciplinary actions for the first time.

In the past several years a number of "outsiders" have attended the academies, either as visitors or as students. They were from out-of-state, from another agency, or perhaps from another unit in the Department of Transportation. The feedback from these visitors has been very favorable.

Many students have commented that this training has introduced them to subjects and methods used elsewhere in the state that they had never heard of before. This is logical, since the course is tailored from material taken from practices employed in all 11 districts. Another important point is that the student recognizes his weaknesses in certain subjects and in many cases is motivated to overcome them.

The "vital shift"—the promotional advancement in a maintenance career from a worker to a manager, from a "doer" to a "delegator", from a field atmosphere to an office atmosphere, from a line boss directing one or two crews to a manager coordinating the efforts of many line supervisors—is being accomplished by the academy approach to training.

The gathering of a broad spectrum of employees in an academy atmosphere results in identification of additional training needs. As a consequence, we have three additional training programs under way, which are briefly described in the following.

MAINTENANCE MANAGEMENT SEMINARS

California, like many other states, is presently in the implementation stage of a maintenance management system. This system is composed of the major components present in all systems, such as quality standards (levels), inventory items, work standards, work programs, activity identification, and budgeting and reporting. Our management system is in its third year of implementation. The goal for full implementation is July 1, 1975.

No system will realize its full benefits unless it is used, and supervisors must be trained to utilize the tools a modern management system provides. This need is being met by creation of maintenance management system seminars. The seminars consist of 4-day sessions using the live-in academy training approach. All maintenance supervisors from the foreman level to the district chiefs of maintenance will have been trained in system use by the end of 1974.

Figure 3 shows the subject matter covered in these seminars.

MAINTENANCE BASIC SUPERVISION COURSE

The three previously described training programs do not adequately cover the very important area of human relations. Present-day first-line maintenance supervisors face many new employee-related problems that cannot be solved by the old-time "straw boss" approach. We are living in a more permissive age, and the foreman must consider this when dealing with his subordinates. Employee organizations are growing and are having greater voice in overall working conditions. Foremen must keep themselves informed and respond in an appropriate manner to problems in this area.

In the past, human relations training was provided by a generalized basic supervision course designed for all supervisors in the Department of Transportation. Since this course was not adequate in helping the maintenance foreman solve his employer-employee problems, a course has been developed that is tailored strictly to his needs.

The course is being given to groups of maintenance supervisory personnel in all 11 districts. Trainers are maintenance supervisors who have completed an instructors' training course.

Figure 4 shows the subject matter contained in this 40-hour course.

MAINTENANCE CORRESPONDENCE COURSES

Below the foreman level most training is accomplished by on-the-job training, with foremen passing their knowledge and skills on down the line. However, additional training needs were identified in basic fundamentals of both a technical and administrative nature. Maintenance correspondence courses were created in 1970 with the primary objective of reducing maintenance costs by increasing the employees' knowledge and proficiency of maintenance operations. In providing these courses it is planned to

1. Minimize the on-the-job training required for new personnel;
2. Update and refresh the basic maintenance knowledge of more experienced personnel; and
3. Provide maintenance knowledge in subjects not easily available to some personnel because of job assignments or location.

Home study courses for landscape employees are presently being prepared.

Figures 5 and 6 show the correspondence courses and indicate the wide range of subjects covered in the series. As a home study course, the time spent by the employee is his own. Some 2,700 of the maintenance employees in California are working on the correspondence courses at this time, and approximately 400 have completed the road maintenance courses to date.

There have been accumulated savings of approximately 1,500 man-years and $23 million in the last 4 years attributable to our maintenance management system. We feel that a portion of this savings has been due to the instructions and training given at our academies and seminars.

California's maintenance training programs are very ambitious. We have always been of the opinion that the caliber and actions of our maintenance people are the best advertisement a highway organization has. This is especially so in the more remote areas or where the local foreman or superintendent <u>is</u> the Department of Transportation in the eyes of the people we serve.

DISCUSSION

G. M. Briggs, New York State Department of Transportation

The paper by Wilson and Smith indicates that California recognized that a problem existed and systematically set out to devise a solution. This is certainly the most ambitious, sophisticated, and complete training program in operation that I have seen for maintenance personnel.

Figure 3. Maintenance management system seminar schedule.

MONDAY

- Current Status of MMS
- Quiz
- Reporting Revisions
- Equipment Management
- Quiz Critique

TUESDAY

- Reporting
- Inventory
- E.D.P. Processing
- Annual Work Load Plan
- Organization

WEDNESDAY

- Management & Cost Reporting System (overview)
- Report Analysis
- Presentation of Analysis
- Biological Control
- Human Relations

THURSDAY

- Quiz
- Letter Writing
- General Discussion

Figure 4. Maintenance basic supervision course subject matter.

- Interpersonal Relationship
- Public Relations
- Relationships with Employee Organizations
- Communications
- Team Development
- On-The-Job Training
- Discipline and Punitive Action
- Grievance Procedure
- Interviewing Prospective Employees
- Special Employment Programs
  1. Career Opportunity Development
  2. Employing the Underprivileged
- Employee Motivation
- Cultural Awareness

Figure 5. Maintenance correspondence courses available.

VOLUME 1

- Aggregate Bases and Subbases
- Asphalt Concrete and Liquid Asphalts
- Blasting

VOLUME 2

- Bridges
- Concrete
- Guardrail
- Median Barrier and Right of Way Fence
- Painting
- Personnel
- Pollution Control
- Public Relations
- Safety

VOLUME 3

- Signs and Pavement Delineation
- Snow Removal
- Traveled Way, Shoulders, and Drainage Structures

SEPARATE VOLUMES

- Practical Mathematics Review
- Plan Reading

Figure 6. Landscape correspondence courses available.

VOLUME 1 (completed)

- Botany

VOLUME 2 (being prepared)

- Biological Control
- Safety
  - Safety Attitudes
  - Safety Organization
  - Traffic Control
  - Eye Hazards
  - Highway Spills
  - Pesticide Safety
- Watering Methods

VOLUME 3 (being prepared)

- Turf Management
- Tree Trimming
- Shrub Pruning
- Chemicals (pesticides)
- Fertilizers

VOLUME 4 (being prepared)

- Plant Pests and Diseases
- Weeds
  - Identification
  - Methods of Control

California has controlled the training environment by establishing a maintenance training academy where personnel can be isolated from work-related distractions. The course is highly structured to contain those subjects that were considered to be the most vital to the organization. The inclusion of an expert staff and the element of competition seem to ensure the success of this effort.

After a discussion with representatives of the California Department of Transportation some 4 or 5 years ago, New York State Department of Transportation instituted a similar program for our maintenance engineering personnel. Without the benefit of a department facility, our effort to remove personnel from their work environment had to involve motels and available space at the main office for classrooms. A 3-day program for our highest level of foremen was instituted. This program was offered at locations throughout the state, but not at work locations. These programs have been well received by the participants.

My comments are addressed to maintenance training in general and do not apply specifically to the subject paper. Examination of the courses covered in all these programs indicates a trend in maintenance training that reflects the concern of management about maintenance. Courses offered are in administration, supervision, cost estimating, budgeting, and planning. No longer are subjects covered that relate directly to the physical acts of maintenance or maintenance technology. What needs repairing, how to repair it, and the correct use of equipment and materials are relegated to the backgrcund of the training effort, if indeed they are covered at all. Is this a trend that emphasizes form over substance, paper over product, and makes the data processing machine the master rather than the tool? Since the greatest savings that can be made in maintenance (outside of some miraculous material development) appear to be in the personnel area, perhaps the need for this direction in training is correct.

There is a question as to just how fast people with various levels of education can absorb training. Many of us have been involved in week-long live-in training sessions that saturate you with information from 8:00 a.m. to 10:00 p.m. We have also observed the tailgate safety sessions lasting 15 minutes. Which is the more effective in altering behavior or performance? Roy Jorgensen Associates, in the course of a contract for the development of a maintenance curriculum, has done extensive research into training of maintenance personnel. The results of this research seem to indicate that a 3-hour training session is the optimum length for the average foreman.

There is nothing more frustrating than knowing a better way to perform and not being able to use it because the hierarchy will not change to new methods. Training thus can only get results if the working environment is receptive to the ideas. It is therefore important that either the existing management be heavily involved in the direction of any training so that the training is compatible with organizational thinking, or, if a new technique, style, or system is to be introduced, that it be introduced, sold, and put into practice at the highest level first and then work its way to the first-line supervisor.

A proper experiment needs a "test section" and a "control section" so that new products or techniques can be compared with a "known". The benefits of training are difficult to quantify, and if we were to withhold funds for training until similar justification was available there would be little training. Nonetheless we should attempt to check if the courses and techniques used are achieving the results we want. Instead of involved attempts to measure dollars saved, we should at least be measuring knowledge gained. This means giving two comparable tests, one prior to training and one after. It is understood that the Jorgensen firm used this technique to prove out its curriculum.

Another problem with training is that it can become too far removed from the operation. When this occurs, we can measure an increase in knowledge as a result of the training but no application of such knowledge to the job. The training then becomes a way to pass exams or a line on the resume, but it has no real bearing on the real world to the man trained. We pay for 8 hours' work and perhaps we could expect that crews will travel for 1 hour and have other nonproductive work such as coffee breaks, setting up time, and personal time to amount to another hour, so that we anticipate 6 hours of working time. If we alert supervisors to the need to achieve this effort and through training in scheduling, supervision, and motivation demonstrate how to achieve it, and then still find we get less than 5 hours' performance, then our efforts have been stopped short of the goal. There is some element that cannot be trained into a supervisor and that is an acknowledgment of his responsibility to see that the owner (or in our case the taxpayer) gets value in return for value given.

John M. Kirtland, Hennepin County Department of Public Works, Hopkins, Minnesota

Historically, the first-line supervisor has been the most neglected segment of our industry. In recent years many have recognized this as a costly and critical oversight and are attempting to correct or improve the condition in a variety of ways. Formal training programs are gaining acceptance, and much work is being done in the area of development.

The basic maintenance supervisor course described in this paper was of great interest to me. The authors made reference to the "vital shift", or the advancement of a doer to a delegator. Foremen for the most part are promoted from the ranks with little or no supervisory skill and generally with little or no concept of the job requirements. The problem of changing basic attitudes of line personnel—men who before promotion relied on the boss for their daily assignments, were union members, and were pals and buddies with their fellow workers—is generally a difficult one. This is a drastic turnabout for the average employee. Now, he is expected to think differently, be dollar- and time-conscious, get a day's work from those previous fellow workers, handle union grievances, administer discipline, make decisions, and be accountable for results. Unless we provide the proper training and guidance, all we can or should expect is another high-priced liaison man or runner.

AUTHORS' CLOSURE

It was noted that, in general, maintenance training is pointed toward administration, supervision, cost estimating, budgeting, and planning and away from subjects that relate directly to the physical acts of maintenance or maintenance technology. This is true of our academy-type training in maintenance and landscape and, to a degree, reflects management's concern in these areas. However, we have developed correspondence courses that cover a wide range of basic knowledge, with direct application to maintaining the roadway and landscaping.

Between the academies, the correspondence courses, the maintenance basic supervision course, and other training available at the district level, we feel that most areas of employee and management needs are being met. The academies and other training approaches are revised or developed as needed to better meet the changing times.

The academy type of training has worked well for us, both for freedom from work-related distractions and for the benefits of bringing together in a central place people from all over the state for a free exchange of ideas. Also, our district maintenance engineers, senior maintenance superintendents, maintenance superintendents, and landscape specialists instruct at the academies and seminars on a rotating basis. This has benefits for both instructors and students.

I agree that further studies are needed to determine the most efficient and effective types of training.

EVALUATION OF THERMOPLASTIC ASPHALT COMPOSITIONS FOR STREET PATCHING

Warren D. Siemens, Public Technology, Inc.,
Washington, D. C.; and
Joseph S. Amstock, Products Research and Chemical Corporation,
Burbank, California

An investigation of a family of thermoplastic asphalt compositions for all-weather permanent street patching applications was conducted by Public Technology, Inc., and Products Research and Chemical Corporation under contract to the National Aeronautics and Space Administration. Ten ethylene-vinyl acetate copolymers were laboratory-tested in different ratio combinations with various penetration-grade asphalts. The physical properties of these compositions were related to the functional requirements for a street patching material established by Public Technology's User Requirements Committee composed of street superintendents, public works directors, city administrators, and others. Two formulations were selected for preliminary field-testing at 3 sites: Burbank, California; South Lake Tahoe, California; and Anchorage, Alaska. The field-test results (after 2 months) indicate considerable promise for the material for emergency patching. A cost-effectiveness analysis indicates that if the new material has a road life twice that of current emergency patching materials then it is as cost-effective as current materials. This is calculated on the basis of total costs (materials, equipment, and labor) averaged from data for 12 cities.

•PREVIOUS work by Jet Propulsion Laboratory and Stanford Research Institute and others indicated that the flexibility, tensile strength, elongation, elasticity, penetration, temperature response, and adhesion of asphalt could be improved significantly by combining the asphalt with ethylene-vinyl acetate (EVA) copolymers such as the Elvax series of resins from Du Pont. It was felt that improved street patching materials could result from utilizing this EVA-modified asphalt in their composition as a binder for the aggregate.

Public Technology, Inc., under contract to the National Aeronautics and Space Administration, employed the services of Products Research and Chemical Corporation to perform the necessary laboratory development work and to provide the pilot-scale materials for field testing EVA-asphalt compositions.

Accordingly, development work was conducted to determine the most promising combinations of EVA resins with asphalt and aggregate for this application. A typical paving asphalt, 85-100 penetration, was combined with 10 different representative EVA resins in a 60/40 weight ratio. The EVA resins used were Elvax 420, 150, 40, 220, 240, 310, 350, 4310, 4320, and EP-4824. These resins differ in their vinyl acetate content, molecular weight, melt index, melt viscosity, solubility, softening point, tensile strength, ultimate elongation, and hardness. The physical and handling properties of each combination were determined. The 5 resins of the first 10 that exhibited the best properties were retested at an 80/20 weight ratio of 85-100 penetration asphalt to EVA resin. These 5 resins were Elvax 150, 240, 420, 4320, and 350. Of these, the Elvax 150 and 420 asphalt combinations were chosen to undergo field testing as the binder for aggregate-filled patching compositions for potholes. These 2 resins tend

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to represent the extremes of cost and of vinyl acetate content, which is related to adhesion and tack. Other properties, such as melt viscosity, tensile strength, ultimate elongation, and hardness, are comparable.

In every instance, the modification of asphalt with EVA resins in amounts of 20 percent by weight or greater resulted in the imparting of significant elastomeric qualities to the asphalt.

Field test applications were conducted in 3 locations: Burbank, California; South Lake Tahoe, California; and Anchorage, Alaska. The last 2 were chosen because of severe freeze-thaw weather cycles, which it was felt would be a critical factor in the success of any patching composition. At each site, dish-shaped potholes 16 to 18 in. (41 to 46 cm) in diameter and from 4 to 6 in. (10 to 15 cm) in depth were cut into existing pavement in the wheel track. Two premixed binder-aggregate compositions were used in the field tests. Each consisted of 5 percent by weight Elvax 150 or 420 binder (80/20 85-100 penetration asphalt/EVA resin) and 95 percent dense-graded aggregate. At each test site, the premixed materials were supplied cold in 5-gallon pails and had to be heated to 260-300 F (127-149 C) before using.

With each premixed composition, 4 types of potholes were patched: dry, wet with water, dry and primed, and wet and primed. The primer used was a 60 percent solids 80/20 85-100 penetration asphalt/Elvax 40 combination. Heating the premixed materials to proper application temperatures at the test site proved to be a problem. Only the Department of Public Works at Burbank, which happened to have a large walk-in oven, was suitably equipped for heating the material in the form supplied. At the other sites, considerable improvisation was necessary.

The premixed material, when heated to the proper temperature, was applied in much the same manner as conventional hot-mix asphalt. As many 2-in (5-cm) courses as required to patch the hole were hand-tamped in place. A heated roller was used to finish off the top layer.

A limited number of potholes were patched using a layering technique. This technique consisted of pouring alternate layers of cold or hot aggregate and hot liquid binder.

The performance results of the patches have been monitored and compared to standard asphalt patching materials put down at the same time to serve as controls. In every instance, the standard hot-mix patching material is performing as well as the Elvax 150-based composition and slightly better than the Elvax 420-based composition. The most significant mode of failure to date has been a raveling of the material at the edges. No significant differences have appeared between wet and dry holes. Only between primed and unprimed holes have differences appeared; primed holes tend to show significantly less edge raveling than unprimed holes. These results, however, are based on a test period of only 2 months.

In the case of potholes filled by means of the layering technique, incipient failure through dishing caused by compaction of the aggregate was rapidly apparent.

The application requirements for patching materials containing EVA-modified asphalt were investigated; these included packaging types and configurations, equipment needs, and methods of application.

Supplementary laboratory work was performed to evaluate Elvax 150 and 420 as a 20 percent weight modification of 40-50 penetration and 200-300 penetration asphalt so that regional variations in grade of available asphalt and in climatic conditions might be taken into account. The 40-50 penetration asphalt was found to give a tough, dry, leathery elastomeric material, well-suited to regions with hot summers and mild winters. The 200-300 penetration asphalt gave a comparably weak, soft, sticky elastomeric material of little utility.

Elvax 150, 350, and 420 were also evaluated as a 10 percent weight modification of 85-100 penetration asphalt with a view to determining the lower limits for significant property modification of asphalt with EVA resins. In each case, extremely soft, sticky, plastic materials of little elastomeric quality were obtained.

The adhesion of the standard Elvax 150 and 420 combination with asphalt (80/20 85-100 penetration asphalt/EVA resin) to samples of asphalt pavement from different cities was tested and found to be good, with no significant differences.

Supplementary field testing was conducted in Burbank by the Public Works Department to evaluate an experimental heater-mixer derived from a small portable cement mixer. On-site heating and mixing of aggregate with binder was attempted with good results. Reheating of cold, crushed premixed material was also attempted, again with good results.

The use of EVA-modified asphalts as a crack filler was investigated. Twenty percent weight modifications of 40-50 penetration asphalt with Elvax 420, 85-100 penetration asphalt with Elvax 420, and 85-100 penetration asphalt with Elvax 150 were used. The results thus far are quite encouraging.

A small-scale preliminary feasibility study of 2 possible routes for the large-scale production and distribution of EVA-modified asphaltic materials was made. Material sources, equipment requirements, and manufacturing quality control methods were outlined.

The results of this program indicate that the physical properties of asphalt, such as tensile strength, ultimate elongation, penetration, adhesion, and low-temperature susceptibility, can be significantly improved by modification with suitable amounts and types of EVA resins.

SPECIFICATION OF THE PROBLEM

Asphaltic concrete is a relatively brittle, unyielding material. When subject to the normal expansion and contraction cycles caused by alternate heating and cooling during its day-to-day exposure to the elements, it has a tendency to crack rather than to give. These cracks then become the site for abrasion and degradation and for the entry of water, which, upon freezing, will induce further failure in the roadbed. These failures are known as "chuckholes" or "potholes". Beyond being an irritant or nuisance to drivers, they can be a hazard to vehicular traffic. The emergency repair and maintenance of these potholes is a significant problem for all state, county, and local governments. The problem is particularly severe in areas with a high water table, which weakens the roadbed and makes it more susceptible to potholing, and in areas of repeated freeze-thaw cycles, which also accentuate the development of potholes.

The problem that state and local government street maintenance authorities are faced with is the fact that there is no truly effective all-weather emergency patch available to them. The "hot mix", which is the preferred solution, duplicates the material content of the roadbed itself and provides an adequate patch; however, during cold or inclement weather, the hot patch cannot be used. It will not adhere to a wet hole and is generally unobtainable during the winter months in the colder climates. Local hot-mix plants shut down during cold months inasmuch as there is very little call for the material because it cools so much during shipment to the repair site.

The cold-mix materials that are available for winter application also suffer from the problem of incompatibility with wet surfaces. This problem is further accentuated by the fact that, for a number of reasons, the cold-mix material degrades very quickly and generally must be replaced several times before the end of the winter season.

With current materials and technology, road and street patching is an expensive operation. It is estimated that about $800 million is annually spent for materials and equipment in municipalities, counties, and states for road and street maintenance. Further, patching and resurfacing is a labor-intensive activity, with most of the total cost of maintenance being devoted to labor. The bulk of the $800 million figure applies to municipalities and counties, with a small portion attributed to the states. It should be noted that this is a conservative figure because of the unavailability of cost data for these operations at the various local governmental levels and the consequent requirement for estimates based on sampled city, county, and state cost data.

The development of an effective, all-weather street patching material not only would provide benefits to the cost of street maintenance but also would be a public service in that fewer streets and roads would be closed to traffic and for less time. The requirement to redo emergency repairs (as many as 15 times during the course of the winter) could potentially be eliminated. Also, in addition to providing an effective pothole patching material, focus should be made on lateral applications for the developed material in the areas of crack filling and resurfacing.

The performance requirements for an all-weather, permanent street patching material for flexible and rigid pavements were developed by a User Requirements Committee convened by Public Technology, Inc. The scope of the requirements definition included surface patching, crack filling, and pothole patching operations. The products and/or processes developed were to result in a system for which the total street patching operation is more cost-effective than provided by currently existing technology.

Two factors were to determine the cost-effectiveness of street patching operations: first, the availability of a permanent patching material that can be applied in all (or most) weather conditions, thus avoiding the costly process of replacing emergency patches put down in cold and/or wet weather; second, a material that can be applied more productively, i.e., the material should require less man- and equipment-hours per repair site.

A next step in more precise requirement specifications was to relate each requirement to laboratory test procedures. The User Requirements Committee agreed that current asphalt tests are inadequate and in some cases inappropriate for rubberized asphalts. This statement is corroborated by a recent report (1) in which it is recommended that new test procedures be developed for rubberized asphalts and in which several improved tests are suggested.

The requirements set forth are divided into economic, operational, and material requirements.

Economic Requirements

1. The cost constraints of the material are related directly to the effectiveness of the material as an all-weather permanent patch and to the productivity increase in man- and equipment-hours required per pothole repaired. A high percentage increase in material costs can be offset by a relatively low percentage decrease in labor costs.
2. The material should be more durable than standard emergency repair mixes. Durability is primarily related to the ability to remain in the pothole a minimum of 2 seasonal cycles. However, the exact duration required will depend on total cost/performance trade-offs.

Operational Requirements

3. Material application should minimize traffic disruption. Therefore, procedures at the scene should be simple, not involving complex application methods or more total pieces of equipment than current procedures, and time-to-bear-traffic should be minimized. Barricades should be required only when the crew is at work at the scene. This implies that material should bear traffic in about 10 to 20 minutes.
4. The material should be easy to store and packaged in reasonably sized, easy-to-handle configurations.
5. The material should have a sufficient shelf life—a minimum of 1 seasonal cycle.
6. The material should be applicable in ambient temperature ranges from -20 to 120 F (-29 to 49 C).
7. The material should be applicable to wet potholes, with little or no pothole preparation required.
8. Material application should not be potentially dangerous to crew in terms of toxic fumes, flash point, or other dangers to health and safety.
9. The material and its application should not cause significant air pollution or water pollution from leachate runoff.
10. The material should not require elaborate mixing and heating procedures at the scene, and, if possible, the process should use commercially available equipment.

Material Requirements

11. The material should be less susceptible than currently available materials to temperature variations for a number of properties such as flexibility, ductility, penetration, and viscosity.
12. The material should have increased flexibility over a wide temperature range so

that the patch is less affected by expansion and contraction or shifting of pavement surface and base structures.

13. The materials should have increased adhesion and bonding to edges of pothole or surface of pavement (in surface patching) and to aggregate and chips.

14. The material should have comparable resistance to both abrasion and penetration.

15. The material should have decreased permanent plastic deformation under stresses and strains; i.e., the stress/strain curve should be time-dependent.

16. The material should be resistant to deicing chemicals and at least as resistant to petrochemicals as surrounding pavement.

17. The material should not degrade under sustained heating for at least 1 work shift; similarly, material should not degrade significantly upon reheating the material at least once prior to application.

LABORATORY DEVELOPMENT

This work has as its scope the area of thermoplastic asphalt street patching compositions and is limited to combinations of ethylene-vinyl acetate copolymers with asphalt and with or without aggregate.

Chemically, ethylene-vinyl acetate copolymers (or EVA resins, as they are often called) are divided into 5 main groups, 4 of which differ primarily in their acetate content. The fifth group differs from the others in that its members are all acid terpolymers, that is, they contain acid groups interpolymerized with ethylene and vinyl acetate to impart improved adhesion to polar substrates. Previous development work in the area of EVA-asphalt compositions by the Stanford Research Institute employed the Elvax series of EVA resins. For comparative purposes, the Elvax resins were used in this development work. Keith Brinker and George Rears of E. I. du Pont de Nemours and Company, specialists in the ethylene-vinyl acetate copolymers used, gave us the technical insight into thermoplastic asphalt that permitted a successful material to be developed. Their contributions were all donated to the project by Du Pont.

Four grades of paving asphalt from the Newhall Refinery at Newhall, California, were chosen for evaluation. These grades were 40-50, 85-100, 120-150, and 200-300 penetration.

The first phase of the evaluation of EVA-modified asphalt was conducted using 85-100 penetration asphalt with EVA resins in a 60/40 weight ratio; 85-100 penetration asphalt was used because it is one of the grades most often used in asphalt pavement. The 60/40 weight ratio has its origins in suggestions made by the Stanford Research Institute, which conducted earlier research in this area.

Various mixing procedures were tested. The optimum procedure consisted of heating the asphalt to approximately 50 F (28 C) above the softening point of the Elvax resin and then slowly adding the pelletized resin with constant mixing using a Mooney Disperser blade, which is similar to a Cowles Dissolver blade. The mixing time tended to be proportional to the melt index of the resin and inversely proportional to its vinyl acetate content. For most resins, a mixing time of 10 to 12 minutes at a speed of 800 to 1,000 rpm was sufficient to ensure complete uniformity. Those resins with softening points above 250 F (121 C) were much harder to work with than those with softening points below that temperature. In fact, Elvax resin EP-4824 [softening point = 340 F (171 C)] proved almost intractable even at temperatures in excess of 400 F (204 C).

An in-process uniformity test was devised. This test consists of drawing samples of the hot liquid mix from time to time and spreading the material over silicone-impregnated paper or metal, mold-released with a Teflon spray. When the sample has cooled and acquired an elastomeric nature, it is stretched manually in several directions until it is thin enough to be translucent. If striations or granularity are observed, mixing is continued until the material is homogeneous and uniform in appearance.

Each of the ten 60/40 asphalt/Elvax resin combinations was evaluated for handling properties. This consisted of noting the ease of mixing to uniformity at the mix temperature, observing tendencies toward phase separation after 16 hours at 300 F (149 C), and judging tractability or ease with which the mixed material could be worked. Generally, resins of high vinyl acetate content tended to mix in more readily than those of low vinyl acetate content and showed no tendency toward phase separation. Resins of low vinyl acetate content (below 18 percent) did show some phase separation but not enough to be regarded as significant. Resins of low softening points and, hence, high melt indices tended to mix in more readily than those of high softening points and low melt indices. All the resin-asphalt combinations could be handled readily with two exceptions. Elvax 350 proved moderately difficult and Elvax EP-4824 very difficult to handle. This result is due to a combination of high melt viscosity and high softening point.

The physical properties of each of the 10 asphalt-Elvax resin blends were determined. These properties included melt viscosity, penetration at 77 F (25 C) and at 32 F (0 C), Shore A hardness, tensile strength, elongation at break, 100 percent modulus, and tear strength. Table 1 gives the results of these tests. Testing methods used were ASTM except as otherwise noted in Table 2.

Several methods for incorporating the EVA-resin modified asphalt with aggregate were investigated. Hot, liquid EVA-modified asphalt—in this case a 60/40 blend of 85-100 penetration asphalt with Elvax 420—was alternately mixed with cold aggregate, poured over cold aggregate, mixed with hot aggregate, and poured over hot aggregate. Only the last 2 had any promise. Pouring the hot, liquid modified asphalt over hot aggregate had interesting possibilities for repairing potholes. Conceivably, alternate layers of hot EVA-modified asphalt with hot aggregate resulted in a material with much the same handling characteristics and appearance of conventional hot-mix asphalt. A 5 percent addition of EVA-modified asphalt to an aggregate composition conforming to Type IV-b dense-graded mix gave a material of substantially improved flexibility at 77 F (25 C) when compared with a 5 percent addition of 85-100 penetration asphalt to the same aggregate.

Based on the work thus far conducted, certain key performance parameters became apparent. These parameters consisted of the cost of the EVA resin versus improvement in physical properties of the asphalt, melt viscosity at 300 F (149 C), tensile strength and ultimate elongation, penetration at 77 F (25 C), which is related to low-temperature susceptibility and handling properties based on phase separation tendencies, ease of mixing, and tractability.

Using these key performance parameters, one of each of the 5 groups of Elvax resins was selected for further testing at a 20 percent modification level with 85-100 penetration asphalt. These Elvax resins were Elvax 150, 240, 420, 4320, and 350. Handling and physical properties were evaluated in a manner identical to previous combinations. Table 3 summarizes these physical properties.

The 5 Elvax resins that were rejected were done so for the following reasons:

1. Elvax 40—excessive cost when compared with improvement in physical properties;
2. Elvax 220—high cost, poor physical properties;
3. Elvax 310—high cost, very poor physical properties;
4. Elvax 4310—very high cost, very poor physical properties; and
5. Elvax EP-4824—poor handling and application properties due to very high melt viscosity, material very difficult to mix.

Because adhesion to existing asphalt pavement is a prime requirement for a patching material, a suitable test was devised. This test consisted of cutting rectangular blocks, approximately 1½ × 1½ × 3 in. (38 × 38 × 76 mm), from a slab of asphalt pavement. A thin layer of hot liquid EVA-modified asphalt was spread across the center half of each of the rectangular faces of 2 blocks. The coated faces were then pressed quickly and firmly together with the long axis of each block at right angles to the other. The blocks were then stabilized at the desired test temperature [77 F or 0 F (25 C or -18 C)] for 24 hours before testing. Once stabilized, the blocks were placed in an Instron tester and pulled apart at a crosshead speed of 0.05 in. per minute (0.127 mm per minute). The force per unit area required to separate the blocks, the nature of the failure whether adhesive or cohesive, and the jaw separation at failure all are indicative of adhesion and were recorded. The five 20 percent Elvax resin modifications of 85-100 penetration asphalt were tested in this manner with the results given in Table 4; 85-100 pene-

Table 1. Physical properties of 40 percent weight modifications of 85-100 penetration grade asphalt with Elvax resins.

Elvax Resin	Viscosity at 300 F (149 C), poises	Hardness, Shore A	Penetration at 77 F (25 C)	Tensile Strength, psi (kg/cm²)	Tear Strength, lb/in. (kg/cm)	100 Percent Modulus, psi (kg/cm²)	Elongation, percent
40	208	20	41	158 (11.06)	24 (4.29)	28 (2.0)	1,150
150	272	25	33	204 (14.28)	35.5 (6.34)	35.5 (2.49)	1,175
220	101	35	29	94 (6.58)	32.5 (5.70)	54.5 (3.82)	900
240	144	41	26	260 (18.20)	52.2 (9.32)	69.6 (4.87)	1,000
310	69	27	42	3 (2.17)	16.5 (2.95	30 (2.10)	175
350	544	48	23	269 (18.83)	62 (11.07)	94 (6.58)	975
420	208	48	24	98 (6.86)	41.4 (7.39)	88 (6.16)	250
4310	91	27	41	52 (3.64)	12.3 (2.20)	52 (3.64)	100
4320	208	38	30	62.3 (4.36)	26.8 (4.78)	57 (3.99)	350
EP-4824	880 at 400 F (204 C) only	72	11	207 (14.49)	72.3 (12.91)	179 (12.53)	250

Table 2. Laboratory test methods.

Property	Method	Remarks
Viscosity	–	HBF Brookfield Viscosimeter; spindle 3 at 10 rpm; temperature of material: 300 F (149 C)
Hardness	ASTM D 2240	
Penetration	ASTM D 5	Penetration at 100 F (38 C); 50 g weight, 5 seconds Penetration at 77 F (25 C); 100 g weight, 5 seconds Penetration at 32 F (0 C); 200 g weight, 5 seconds
Tensile strength	ASTM D 638	
Elongation	ASTM D 638	
Tear strength	ASTM D 638	
100 percent modulus	ASTM D 638	
Interfacial adhesion	–	As described in report
Uniformity	–	As described in report

Table 3. Physical properties of 20 percent weight modifications of 85-100 penetration grade asphalt with Elvax resins.

Elvax Resin	Viscosity at 300 F (144 C), poises	Hardness, Shore A	Penetration 100 F (38 C)	Penetration 77 F (25 C)	Penetration 32 F (0 C)	Tensile Strength, psi (kg/cm²)	Tear Strength, lb/in. (kg/cm)	100 Percent Modulus, psi (kg/cm)	Elongation, percent
150	14.4	15	127	95	9	32 (2.24)	10.2 (1.82)	10 (0.7)	1,550
240	16.0	22	76	61	9	35.8 (2.50)	13.8 (2.46)	22 (1.54)	1,250
350	21.6	30	50	42	9	155 (10.9)	13.0 (2.32)	48 (3.36)	1,050
420	19.2	35	56	32	8	28 (1.96)	10.5 (1.88)	—	90
4320	22.4	17	123	57	11	18 (1.26)	8 (1.43)	17 (1.19)	500

Table 4. Interfacial adhesion of 20 percent weight modifications of 85-100 penetration grade asphalt with Elvax resins using Burbank pavement blocks.

Elvax Resin	Force Required to Separate Blocks, psi (kg/cm²)	Nature of Failure
150	19 (1.33) at 77 F (25 C)	100 percent cohesive failure in binder
	124 (8.68) at 0 F (-18 C)	85 percent cohesive failure in binder, 15 percent cohesive failure in pavement
240	44 (3.08) at 77 F (25 C)	95 percent cohesive failure in binder, 5 percent adhesion failure to pavement
	156 (10.92) at 0 F (-18 C)	90 percent cohesive failure in binder, 10 percent adhesion failure to pavement
350	34 (2.38) at 77 F (25 C)	98 percent cohesive failure in binder, 2 percent adhesion failure to pavement
	96 (6.72) at 0 F (-18 C)	95 percent cohesive failure in binder, 5 percent adhesion failure to pavement
420	20 (1.40) at 77 F (25 C)	100 percent cohesive failure in binder
	180 (12.60) at 0 F (-18 C)	85 percent cohesive failure in binder, 15 percent cohesive failure in pavement
4320	12 (0.84) at 77 F (25 C)	100 percent cohesive failure in binder
	156 (10.92) at 0 F (-18 C)	100 percent cohesive failure in binder
Control	22 (1.54) at 77 F (25 C)	100 percent cohesive failure in binder
	90 (6.30) at 0 F (-18 C)	100 percent cohesive failure in binder

Note: All specimens pulled at a crosshead speed of 0.05 in. (0.127 cm) per minute.

tration asphalt was used as a control. As can be seen, the modified asphalts exhibited superior adhesion. In fact, in some of the 0 F (-18 C) tests, cohesive failure occurred within the pavement itself. Of special interest is the comparison between the force/distance curves of modified and unmodified asphalt. The areas under these curves are the amounts of work required to separate the blocks. Figure 1 shows that considerably more work is required to separate blocks bonded together with modified asphalt than with unmodified asphalt. Again, this is an indication of superior adhesion. Of course, it must be borne in mind that the results of these types of tests are only relative and not absolute because of the highly variable nature of cross sections of asphalt pavement.

Another type of test was devised to demonstrate the differences in temperature-susceptibility between modified and unmodified asphalt. This test consisted of measuring the penetration of modified and unmodified asphalt at temperatures of 100 F (38 C), 77 F (25 C), and 32 F (0 C) using weights of 50, 100, and 200 grams respectively for 5 seconds each. Figure 2 shows that the modified asphalts have much flatter penetration curves or profiles than 85-100 penetration asphalt, which indicates lower temperature-susceptibility.

Based on the various test results, cost considerations, and handling properties, it was decided that a 20 percent weight modification of 85-100 penetration asphalt with Elvax 150 and with Elvax 420 would be used for field testing, both with and without aggregate. These two resins tend to impart the best physical properties to asphalt while maintaining good handling properties. In addition, they represent to a large extent the extremes of cost and of vinyl acetate content, which is related to tack and adhesion.

Current street patching techniques advocate the use of a tack-coat or primer for the sides of a pothole before the patching material is installed. Typically, emulsified asphalt is used. For the purposes of field testing, it was decided that a suitable EVA-asphalt primer should be developed and tested concurrently with the patching compounds themselves. This primer had to meet the requirements of adhesion to wet and dry asphalt pavement, compatibility with the patching material, and applicability at low ambient temperatures without heating. Such a primer was made from a 20 percent weight modification of 85-100 penetration asphalt by Elvax 40 with the combination reduced to 60 percent solids with xylene.

Manufacturing processes for the production of large quantities of both aggregate-filled and unfilled EVA-modified asphalt were developed. Five-gallon quantities of the EVA-modified asphalt could be produced using a Mooney mixer. The asphalt was first heated and then weighed into a 6-gallon (22.7-litre) container fitted with a 3,000-watt snap-on band-type pail heater. The asphalt temperature was brought up to 300 F (149 C) with a slow stirring. When the temperature was reached, the Elvax resin pellets were added slowly while mixing at 400 to 500 rpm. After all the resin was added, the mixing speed was increased to 700 to 800 rpm and maintained until results of the uniformity test discussed earlier were satisfactory. Typical mixing times at the higher speeds ranged from 5 to 10 minutes.

For mixing the modified asphalt with aggregate, a steam-jacketed rotating vertical blade mixer of 80-gallon (303-litre) capacity proved satisfactory. The aggregate could be preheated to 300 F (149 C) by placing it in drums in a large walk-in oven for several days or by using the steam jacket on the mixer to heat the exact amount required. The aggregate type used was one conforming to the Standard Specification for Public Works Construction 203-6.3.1 Class F. The modified asphalt or binder portion of the mixture was heated separately to 300 F (149 C) and added to the hot aggregate while mixing. Within 7 to 10 minutes, the binder had completely and uniformly wetted out the aggregate.

The aggregate/binder mix ratio was 19/1 by weight. Before filling into 5-gallon pails at 60 lb (132 kg) each, the mixed material was checked for appearance and uniformity and was satisfactory. In this manner, 1,500 lb (3300 kg) of each Elvax resin-asphalt-aggregate composition was made in 500-lb (1100-kg) batches.

Additional development work of a supplementary nature was conducted. This consisted of evaluating Elvax 150 and 420 as 20 percent modifications of 40-50 and of 200-300 penetration asphalt. This was done with a view to developing EVA-modified asphalts that would take into consideration the grade of asphalt available locally and the service temperature requirements. Table 5 shows that the lower penetration grade asphalt

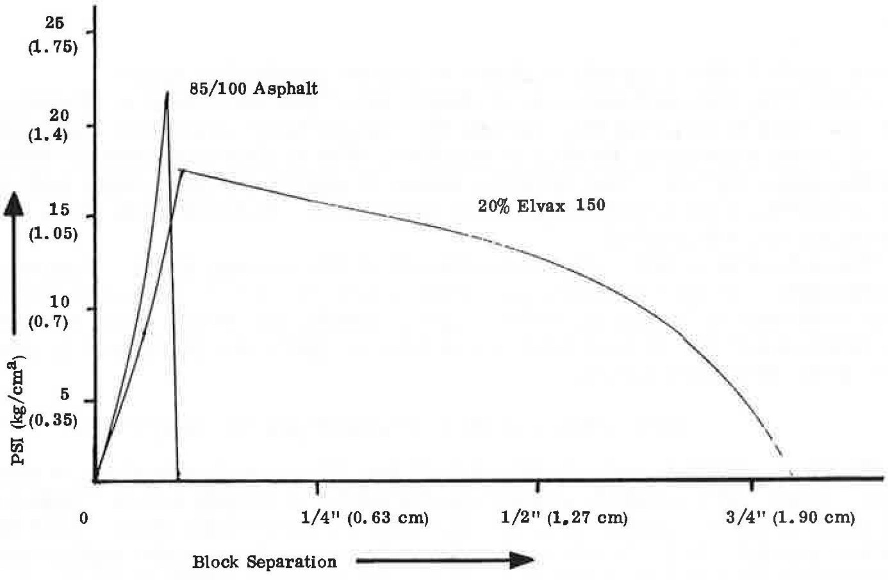

Figure 1. Comparative interfacial adhesion curves at 77 F.

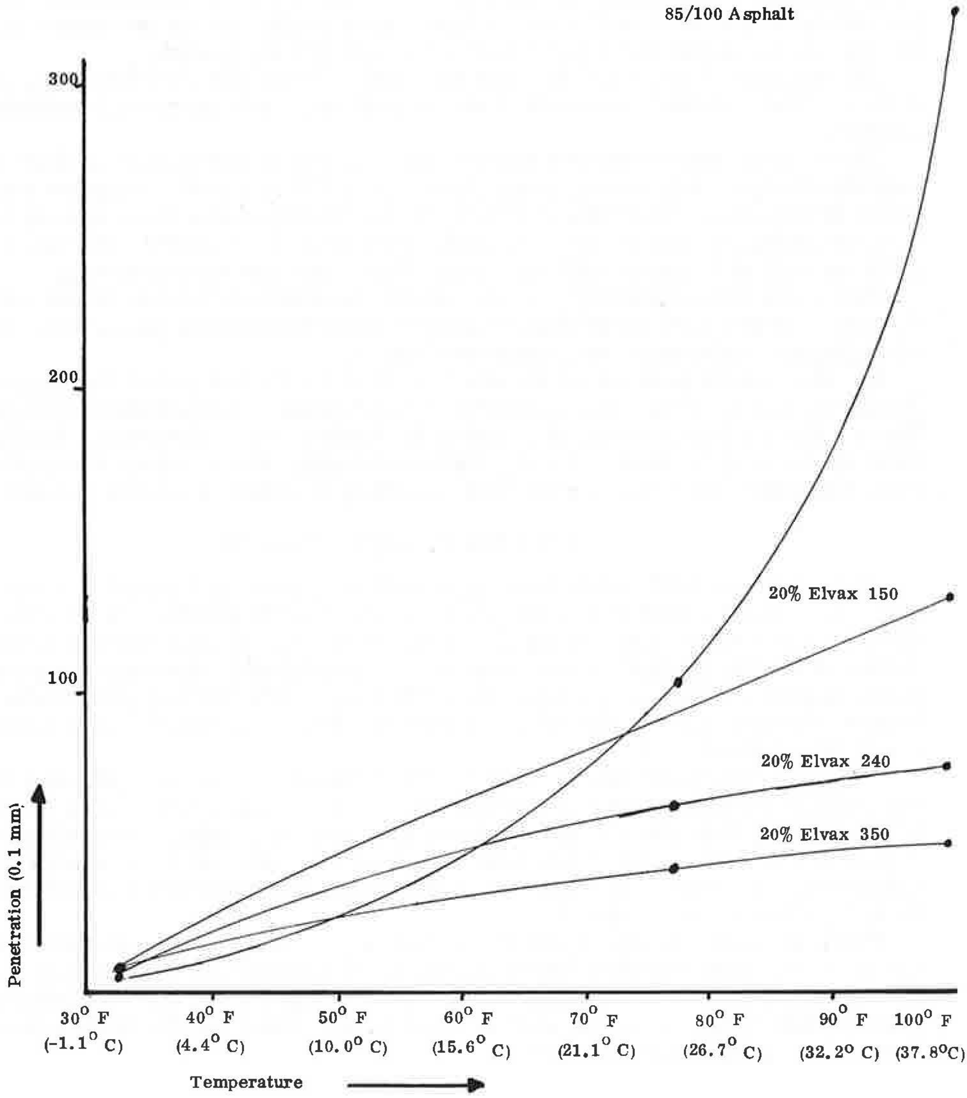

Figure 2. Comparison of penetration profiles of EVA-modified asphalt with unmodified asphalt.

gives much better properties than the higher penetration grade.

Elvax 150, 350, and 420 were evaluated as 10 percent weight modifications of asphalt with the idea of reducing still further the raw material cost of the modified asphalt while maintaining acceptable physical properties. The asphalt used was 85-100 penetration grade paving asphalt. The resulting material was in each case very soft, sticky, and semi-plastic, with ill-defined physical properties. Further study of its suitability for street patching is needed.

The adhesion of the 2 standard modified asphalt compositions (20 percent weight modifications of 85-100 penetration asphalt with Elvax 150 and 420) to pavement samples from Kalamazoo, Michigan, and Winnipeg, Canada, was tested using the block method described earlier. In each case, there was no significant difference in adhesion from that of the Burbank sample.

PRODUCTION AND DISTRIBUTION OF MATERIAL

Three production sources are possible for EVA-modified asphalt patching compositions. On a regional level, an oil refinery would be ideally suited to take advantage of the economies of large-scale production of the EVA-asphalt blend. This blend could then be supplied to local hot-mix plants or to local public works departments for incorporation with aggregate when desired. On an intermediate level, the local hot-mix plant could produce binder and/or premixed material for local consumption. A third possibility is the local public works department producing its own material, either for stockpiling or at the actual patch site using suitable equipment.

Three types of raw materials are required. These are the EVA resin, available from Du Pont, asphalt, available from the refinery, and aggregate, available from local sources.

The kinds of equipment necessary to produce the binder portion include mixers capable of vigorously mixing large quantities of 200 to 10,000 centipoise viscosity material at temperatures of 300 to 325 F (149 to 163 C), heated lines, mixing vessels, and storage tanks, as well as pumps of sufficient capacity. Suitable reservoirs for the asphalt as well as hoppers and bins for the EVA resin are also necessary.

Two types of manufacturing processes are possible—batch and continuous. The former is suited to local producers and the latter to regional producers. Incorporation of aggregate would use conventional equipment.

Quality control procedures involve testing at 3 different points during manufacture. First, all raw materials are checked for conformance with published specifications. Second, the EVA-asphalt blend is tested for hardness or penetration, tensile strength, ultimate elongation, melt viscosity, and uniformity. Third, when combined with aggregate, the mixed material is evaluated according to standard asphalt hot-mix procedures.

APPLICATION OF MATERIAL

EVA-modified asphalt can be made available in several forms depending on the end use. As a premix with aggregate, it can be supplied as precast blocks or as $\frac{1}{4}$ to $\frac{1}{2}$-in. (0.63 to 1.27-cm) granules in sacks. Quite probably, the granulated material would be easier to heat to application temperature. The unfilled binder can be supplied cast into pails, drums, or cartons for later reliquification. Alternatively, the binder can be extruded, chopped, dusted with talc, and sacked. For many applications, this latter form might be the most useful.

The most important requirement for the application of EVA-modified asphalt patching material is suitable heating and mixing equipment. If aggregate-filled premixed material is used, then the minimum requirement is a temperature-controlled oven or heater truck. If bulk aggregate and containers of binder are to be combined at the patch site, then each component may need its own heater unless it is feasible to heat them together in the same unit.

When the proper temperature is reached, each component would then be charged to a mixer and mixed together before applying. A possible alternative here is to charge the aggregate to a heater-mixer, bring it up to temperature, and then add cold, pelletized binder, relying on the heat supplied by the mixer and the aggregate to melt the binder during the mixing process.

Table 5. Physical properties of 20 percent EVA modifications of different grades of asphalt.

Elvax Resin	Asphalt Grade	Viscosity at 300 F (149 C), poises	Hardness, Shore A	Penetration 100 F (38 C)	Penetration 77 F (25 C)	Penetration 32 F (0 C)	Tensile Strength, psi (kg/cm²)	Tear Strength, lb/in. (kg/cm)	100 Percent Modulus, psi (kg/cm²)	Elongation, percent
420	40-50	37	53	62	28	13	66 (4.62)	20 (3.57)	66 (4.62)	1,200
150	40-50	35	16	176	58	22	37 (2.59)	7.55 (1.35)	9.4 (0.658)	1,500
420	200-300	14.8	23	131	57	26	20 (1.4)	6.32 (1.16)	20 (1.4)	600
150	200-300	21	1		98	45	—[a]	—[a]		—[a]

[a]Unable to fabricate specimens; material extremely soft and tacky.

Table 6. Results of field test application at Burbank.

Hole No.	Hole Type	Patch Composition	Appearance[a] 24 Hours	48 Hours	1 Week	2 Weeks	1 Month	2 Months
1	Wet with primer	Elvax 420 premix at 285 F (141 C)	NC	NC	NC	NC	NC	S-SR
2	Wet without primer	Elvax 420 premix at 290 F (143 C)	NC	NC	NC	S-ER	S-ER	S-ER
3	Dry with primer	Elvax 420 premix at 285 F (141 C)	NC	NC	NC	NC	NC	NC
4	Dry without primer	Elvax 420 premix at 280 F (138 C)	NC	NC	NC	S-ER	S-ER	S-ER
5	Dry layer with primer, cold aggregate	Elvax 420 premix at 280 F (138 C)	NC	NC	S-D	B, D	B, D	Replaced
6	Dry layer without primer, hot aggregate	Elvax 420 premix at 280 F (138 C)	NC	NC	S-D	B, D	B, D	Replaced
7	Wet with primer	Elvax 150 premix at 285 F (141 C)	NC	NC	NC	NC	NC	NC
8	Wet without primer	Elvax 150 premix at 285 F (141 C)	NC	NC	NC	NC	NC	NC
9	Dry with primer	Elvax 150 premix at 290 F (143 C)	NC	NC	NC	NC	NC	NC
10	Dry without primer	Elvax 150 premix at 290 F (143 C)	NC	NC	NC	NC	NC	NC
11	Dry layer with primer, cold aggregate	Elvax 150 premix at 280 F (138 C)	NC	NC	D	H-B, H-D	H-B, H-D	Replaced
12	Dry layer without primer, hot aggregate	Elvax 150 premix at 280 F (138 C)	NC	NC	D	S-B, S-D	B, D	Replaced
13	Dry layer with primer, cold ³/₈-in. rocks	Elvax 150 premix at 280 F (138 C)	NC	NC	SR	D	D	Replaced
14	—	Standard hot mix	NC	NC	NC	NC	NC	NC

[a]NC = no change, ER = edges raveling, SR = surface raveling, D = dishing, B = bleeding, H = heavy, S = slight.

Table 7. Results of field test application at South Lake Tahoe.

Hole No.	Hole Type	Patch Composition	Appearance[a] 24 Hours	48 Hours	1 Week	2 Weeks	1 Month	2 Months
1	Wet with primer	Elvax 420 premix at 270 F (132 C)	NC	NC	S-SR, S-ER	S-SR, S-ER	S-SR, S-ER	S-SR, S-ER
2	Wet without primer	Elvax 420 premix at 280 F (132 C)	NC	NC	S-SR, S-ER	S-SR, S-ER	S-SR, S-ER	S-SR, S-ER
3	Dry with primer	Elvax 420 premix at 280 F (132 C)	NC	NC	S-ER	S-ER	S-ER	S-ER
4	Dry without primer	Elvax 420 premix at 275 F (135 C)	NC	NC	S-ER	S-ER	S-ER	S-ER
5	Dry layer with primer, hot aggregate	Elvax 420 premix at 240 F (116 C)	NC	NC	D	D	D	D
6	Dry layer without primer, hot aggregate	Elvax 420 premix at 240 F (116 C)	NC	NC	D, S-ER	D, S-ER	D, S-ER	D, ER
7	Wet with primer	Elvax 150 premix at 300 F (149 C)	NC	NC	NC	NC	NC	NC
8	Wet without primer	Elvax 150 premix at 300 F (149 C)	NC	S-ER	S-ER	S-ER	S-ER	S-ER
9	Dry with primer	Elvax 150 premix at 290 F (143 C)	NC	NC	NC	NC	NC	NC
10	Dry without primer	Elvax 150 premix at 290 F (143 C)	NC	S-ER	S-ER	S-ER	S-ER	S-ER
11	Dry layer with primer, hot aggregate	Elvax 150 premix at 220 F (104 C)	NC	D	D		D	D
12	Dry layer without primer, hot aggregate	Elvax 150 premix at 200 F (93 C)	NC	D	D		D	D
13	—	Standard hot mix	NC	NC	NC		NC	NC

[a]NC = no change, ER = edges raveling, SR = surface raveling, D = dishing, B = bleeding, H = heavy, S = slight.

Table 8. Results of field test application at Anchorage.

Hole No.	Hole Type	Patch Composition	Appearance[a] 24 Hours	48 Hours	1 Week	2 Weeks	1 Month	2 Months
1	Wet without primer	Elvax 420 premix at 265 F (129 C)	NC	S-ER	S-ER	S-ER	S-ER	S-ER
2	Wet with primer	Elvax 420 premix at 265 F (129 C)	NC	S-ER	S-ER	S-ER	S-ER	S-ER
3	Dry without primer	Elvax 420 premix at 265 F (129 C)	NC	S-ER	S-ER	S-ER	S-ER	S-ER
4	Dry with primer	Elvax 420 premix at 265 F (129 C)	NC	NC	S-ER	S-ER	S-ER	S-ER
5	Wet without primer	Elvax 150 premix at 300 F (149 C)	NC	NC	NC	NC	NC	NC
6	Wet with primer	Elvax 150 premix at 280 F (138 C)	NC	NC	NC	NC	NC	NC
7	Dry without primer	Elvax 150 premix at 290 F (143 C)	NC	NC	NC	NC	NC	NC
8	Dry with primer	Elvax 150 premix at 290 F (143 C)	NC	NC	NC	NC	NC	NC
9	—	Standard hot mix	NC	NC	NC	NC	NC	NC

[a]NC = no change, ER = edges raveling, SR = surface raveling, D = dishing, B = bleeding, H = heavy, S = slight.

When it is desired to use straight binder as a crack filler, an oven can be used to heat the containers or a tar kettle to heat the pelletized binder, after charging the desired number of sacks. The premixed material, once it has been brought to temperature, is applied in exactly the same manner as conventional hot-mix asphalt. Holes are swept free of debris and standing water, primed around the edges, and as many 2-in. (5-cm) courses of patching material as necessary are hand-tamped into place, the final course being finished off with a few passes from a heated roller.

FIELD TEST APPLICATIONS

To properly evaluate the performance of EVA resin-modified asphalt patching compositions, test applications under field conditions are necessary. To this end, preliminary field test applications were conducted in Burbank, South Lake Tahoe, and Anchorage. The last 2 sites were chosen for the severe freeze-thaw temperature variations that occur.

At each test site, dish-shaped holes 16 to 18 in. (41 to 45 cm) in diameter by 4 to 6 in. (10 to 15 cm) in depth were cut into existing pavement in a wheelpath. These potholes were then swept free of debris in a cursory manner. Four basic types of potholes were filled at each site: dry with and without primer applied to the sides and wet with and without primer applied. The materials used at each site were aggregate-filled patching compositions using the 20 percent weight modification of 85-100 penetration asphalt with Elvax 150 and with Elvax 420 as the binder. Thus, 2 different patching compositions were tested in 4 different types of holes.

At Burbank and at South Lake Tahoe, additional holes of the 4 types were patched using a layering technique consisting of pouring alternate 2-in. (5-cm) layers of aggregate, ¼ to ⅜ in. (0.63 to 0.95 cm) in size, and hot binder in primed and unprimed holes for both material compositions.

At each test site, a number of holes were patched using materials and techniques that were customary for the individual public works departments. These patches were put down at the same time under the same conditions, as nearly as possible, and were used as controls.

The premixed aggregate-binder compositions were supplied cold in 5-gallon pails and had to be heated to 275 to 325 F (135 to 163 C) before applying. The same requirement held for the straight binder that was supplied in 1-gallon cans for the layering techniques of patching.

The actual application of the materials was accomplished in much the same manner at each site. Only the methods of heating the materials differed. In Burbank, the pails were heated to 325 F in a large walk-in oven and transported under blankets to the site, while cans of binder were heated to the same temperature at the laboratories of Products Research and Chemical Corporation and transported separately as needed. At South Lake Tahoe, conditions were somewhat different. The best piece of equipment available was an asphalt hot-mix transport truck equipped with an electric and propane heated recirculating oil bed heater box. The rate of heat transfer to the material within the pails inside the heater box proved to be very slow. The premixed material was finally brought up to application temperature at the site by charging 2 pails of the material at a time to 2 propane-fired open-top oil-drum heaters and mixing continuously by hand with a shovel to avoid scorching the material. Cans of binder were heated by placing them with the aggregate for the layering approach into the drum heaters and heating them both together. At Anchorage, a large electric oven was made available by the U.S. Army Corps of Engineers Soils Laboratory at Elmendorf Air Force Base. This heating device, too, proved vexingly slow. The premixed material was finally heated by lowering the pails into a vat of hot asphalt at 400 F (204 C) that was part of a truck-mounted small asphalt hot-mix plant. Obviously, equipment requirements need further evaluation.

At each site, the premixed material, when heated to application temperature, was put down in 2-in. (5-cm) courses and hand-tamped until the hole was filled. The top surface was then finished off by passing a heated roller across it several times. The material based on Elvax 420 proved to be more free-flowing and granular in nature when hot than the Elvax 150-based material, which had a tendency to form lumps and clots. As a result, the former was easier to apply than the latter. No significant differences between the handling and application characteristics of the 2 binders were observed when holes were patched using the layering technique described earlier.

The performance results of the test patches at each site were monitored and evaluated. Tables 6, 7, and 8 give the results of 2 months' testing. As can be seen, the durability of Elvax 420-based premixed patches seems less than that of the Elvax 150-based premixed patches, which, in turn, are about equal to the controls. This trend seems more pronounced at the sites with low prevailing temperatures. The chief mode of deterioration is that of slight raveling at edges and on surfaces. Only continued testing will reveal if this deterioration will continue or if it will stabilize. In addition, it is apparent that the use of a primer contributes significantly to the durability of the patch, whether wet or dry holes were filled.

The layered holes at South Lake Tahoe and especially at Burbank are not doing well and have been replaced in Burbank after about 2 months. Holes filled using dense-graded aggregate dished and became concave and exhibited signs of bleeding. Holes filled with coarse, self-locking aggregate are not dishing nearly as much but do suffer from bleeding. The high ambient temperatures at Burbank seem to promote both effects more than the low ambient temperatures of the other sites.

Supplemental field testing was done by the Public Works Department of the City of Burbank. This testing consisted of using the 2 standard binders and a binder consisting of a 20 percent weight modification of 40-50 penetration asphalt with Elvax 420 as a crack filler. Both dry cracks and cracks wet with water were filled with each material, dusted off with sand, and opened to traffic immediately. The initial adhesion to wet cracks was not good, but by the next day it was excellent for all materials. After 2 months' testing, the 20 percent weight modification of 40-50 penetration asphalt with Elvax 420 continued to perform well. The standard Elvax 420 binder is satisfactory over cracks that were dry when filled but is opening up along the length of the crack that was wet when filled. The standard Elvax 150 binder has failed over both wet and dry cracks.

In addition to crack filling, an experimental heater-mixer was evaluated. This device is a small concrete mixer fitted out with a ring of propane burners around the bottom. In one experiment, the aggregate was charged to the heater-mixer and within ½ hour or so the temperature was 300 F (149 C). Preheated binder was then charged to the hot aggregate and mixed with it until uniform and of good appearance, a process which required 7 to 10 minutes. A rectangular saw-cut hole 1 × 2 × ½ ft (30.5 × 61 × 15 cm) was patched with the freshly made material using techniques described earlier.

Another experiment was conducted using the heater-mixer to bring up to application temperature the standard Elvax 150-based premixed material. This material was first crushed in a press to reduce it to small lumps and then charged to the mixer. The time required to reach 300 F was on the order of 1 hour, which is almost twice as long as the aggregate alone. The large size of the lumps—approximately 2 in. (5 cm)—may well have impeded the heat transfer. A hole identical to the first one was filled with the material using the same techniques. Both test patches are holding up well.

COST-EFFECTIVENESS ANALYSIS

A cost-effectiveness analysis was conducted comparing total street patching costs (materials, equipment, and labor) using standard patching materials with total costs using the thermoplastic asphalt material. This analysis was based on cost data collected from 12 cities from various regions of the country and of various population sizes. The analysis is reported in detail elsewhere (2).

The relative cost benefits of 3 alternative cases for processing the material are analyzed: case 1, where the city purchases the EVA, the asphalt, and the aggregate and performs all material processing; case 2, where the city purchases the EVA-asphalt binder and mixes it with the aggregate; and case 3, where the city purchases the material ready-made.

The cost analysis shows that, assuming equal road life of the current and new materials, the costs are as follows:

Method	Annual Total Recurring Cost Per Ton ($)	Initial Equipment Outlay ($)
Current	47.30	None
Case 1	51.94	10,000 + 2,750 per crew
Case 2	81.63	2,750 per crew
Case 3	95.83	2,750 per crew

The road life factor required of the thermoplastic material to be as cost-effective as current materials is as follows:

Method	Required Road Life Factor
Current	1.0
Case 1	1.1
Case 2	1.7
Case 3	2.0

In other words, if the road life of patches using the new material is twice that of current materials, then the new material is as cost-effective as current materials or more cost-effective, depending on the case.

CONCLUSIONS AND RECOMMENDATIONS

Based on the laboratory development work and field test applications done to date, the User Requirements Committee reached the following conclusions:

1. Significantly improved physical properties can be imparted to asphalt by mixing with EVA resins in amounts of 20 percent or more by weight. This includes tensile strength, elongation, and modulus.
2. The quality and quantity of adhesion of EVA-modified asphalt to asphalt pavement is significantly better than unmodified asphalt. This holds true apparently regardless of the regional differences in asphaltic concrete.
3. Improved penetration profile, interfacial adhesion, tensile strength, ultimate elongation, and other elastomeric qualities indicate that EVA-modified asphalt compositions are good candidates for meeting street patching requirements.
4. EVA-modified asphalt patching compositions have not exhibited performance superior to conventional hot-mix asphalt after 1 to 2 months' testing. No empirical data have been obtained regarding cold patch material, since the committee believes the cold patch would not hold at all.
5. The necessity for using more sophisticated heating and mixing equipment reduces the utility of EVA-modified asphalt patching compositions. The cost analysis implies, however, that this is not an excluding condition. The potential savings of increased road-life over emergency patches offsets equipment expense.
6. Preliminary results indicate that a premixed material, pelletized by cooling under noncompacted conditions, may obviate the need for heater-mixer equipment required in the application procedures developed to date.
7. EVA-modified asphalt compositions containing aggregate can be applied and produced in a manner similar to conventional hot-mix asphalt.
8. The use of a primer improves the durability of EVA-modified asphalt patching compositions. This is particularly true in the case of wet holes. The fact that use of primer permits application under wet conditions argues strongly for continued testing and development.
9. Higher vinyl acetate-content EVA resins exhibit better durability in patching compositions than lower vinyl acetate-content resins, although the former are more difficult to apply.
10. Lower penetration grades of asphalt give better physical properties when modified with EVA resins than higher penetration grades.
11. For optimum adhesion, the EVA-modified asphalt patching compositions require a temperature of 260 to 325 F (127 to 163 C) at the time of application.

12. EVA-modified asphalt patching compositions can be reheated and reused several times without significant loss of properties.
13. EVA-modified asphalt has considerable potential as a crack filler.

Based on observation of thermoplastic street maintenance material developed, applied, and tested to date, the following recommendations for directions to be pursued to ultimately create a marketable, cost-effective product are proposed:

1. Research and development on temperature-susceptibility of the material, with particular emphasis on the low-temperature properties, should be continued. Investigations should determine whether it will be possible for a single material to suit both winter and summer conditions or if 2 products will be necessary.
2. Field testing should be continued and expanded. The material should be made available to at least 10 selected cities by next fall, for application during the winter months. The application procedure should be sufficiently defined to lead to installation in high-stress areas such as curbs, bus stops, and turning and stopping zones.
3. Further investigations and field testing should be conducted on the pelletized coated-aggregate technique, which appears to have the potential for overcoming many of the equipment problems associated with the hot-mix material.
4. The quality of the input data on cost should be refined, and a more accurate model for a city to use in determining whether or not introduction of the thermoplastic street patching material would be cost-effective should be developed.
5. Testing of patching compositions already in place at the 3 field sites should continue until such time as the true performance differences among the various materials are apparent.
6. If EVA-modified asphalt patching compositions are to be used as presently constituted, suitable low-cost heating and mixing equipment must be developed. If such equipment is commercially available, its use must be advocated.
7. The use of EVA-modified asphalt as a crack sealer should be thoroughly investigated.

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WATER POLLUTION AND ASSOCIATED EFFECTS FROM STREET SALTING

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ABRIDGMENT

•MOST of the sodium chloride and calcium chloride (hereafter called "salt" or "road salt") used for deicing purposes eventually has a detrimental effect on our environment. The high levels of salt in our drinking water and the effect of the salt on the flora adjacent to highways and roadways have produced doubts about the heavy use of salt to provide "bare pavement".

The "bare pavement" policy of highway maintenance is popular because it is an easy guide for highway crews and because most people believe that it reduces wintertime accidents. The problem with this policy, however, is that is specifies the minimum of salt needed but not the maximum and that it spoils motorists by leading them to expect "June travel in January".

When skidding is the possible cause of an accident, the highway department is at once blamed, regardless of other important possible causes. Because of this, foremen tend to salt heavily and early, even though statistics do not clearly show a positive correlation between road salting and accidents. Several researchers have suggested that heavy salting may even increase or worsen accidents by giving drivers a false sense of security. Also, a bare pavement, especially on bridges and ledge cuts, in cold weather can develop a thin sheet of ice that is invisible to the motorist. Winter road safety may depend more on driver attitudes and behavior than on road conditions.

A 1971 EPA report, Environmental Impact of Highway Deicing, focuses on the characteristics of snowmelt runoff and its effect on the environment. This report also covers snow removal operations and the effects of deicing salts on roadside vegetation, vehicles, and highway structures. Some of these topics are covered briefly here.

Currently about 9 to 10 million tons of sodium chloride, 0.3 million tons of calcium chloride, and 11 million tons of abrasives are used annually. Highway salting rates range from 400 to 800 pounds of salt per mile of highway per application, and many roads annually receive more than 50 tons of salt per mile.

Prescribed application rates vary, but it is acknowledged that, however high or low the prescribed rate, highway crews often exceed the levels of salting recommended by the management. This is due to fickle weather, public demands for snow-free roads, lack of precision spreaders, and poor handling techniques.

Poor methods of loading salt onto trucks and improper calibration and operation of snow control equipment often lead to excessive salt use. New spreading mechanisms (e.g., one that will spread salt in a restricted path or one that will give a constant spread rate geared to road speed) and improved handling practices can minimize environmental problems and save money without impairing wintertime road maintenance.

Deicing salts are often stockpiled in open areas without suitable protection, and if covers exist they are often not properly fastened. The resulting salt-laden drainage

Publication of this paper sponsored by Committee on Snow and Ice Control. The Committee believes that publication of an abridgment is appropriate here because the full report has received wide distribution, and it acknowledges that certain comments by the discussers pertain to the original report and not to the portions included in this abridgment.

often has easy access to nearby water supplies. Treatment of the drainage and the use of covered dome-like structures, like the one called the "beehive", could eliminate salt storage pollution dangers.

Large amounts of accumulated snow and ice, some containing up to 10,000 mg/litre of sodium chloride, 100 mg/litre of oils, and 100 mg/litre of lead, are dumped into nearby waters, or else the snow melts and then runs off and enters the body of water via the sewer system. In Milwaukee, during days of heavy snowmelt runoff, daily chloride loads in municipal sewage were 3 times the normal summertime loads.

A 1966-1968 survey of 27 ponds along various highways in Maine showed that road salts have strong seasonal influences on the chloride level and that these levels are increasing yearly. In addition, the sodium from road salts entering streams and lakes can overstimulate the growth of blue-green algae. Sodium and calcium ion exchange with mercury could, under special sediment conditions, release highly toxic mercury or other heavy metals to the overlying fresh waters.

Ferric ferrocyanide and sodium ferrocyanide, common additives in road salt, are soluble in water and can generate cyanide in the presence of sunlight: 15.5 mg/litre of sodium ferrocyanide can produce 3.8 mg/litre of cyanide after 30 minutes, as compared with public health limits of 0.1 to 0.2 mg/litre. Further research is needed to establish the ultimate fate of these cyanides in the environment.

Groundwater pollution by salt has caused some wells in New Hampshire to contain more than 3500 mg/litre of chlorides, as compared with a U.S. Public Health maximum of 250 mg/litre. Relatively low concentrations of sodium in drinking water can exacerbate hypertension, heart disease, and kidney and liver ailments, diseases that affect many Americans.

Road salt can cause vehicle corrosion and may affect structural steel, house sidings, and other property as well as damage highway structures and pavements. Underground utilities, such as cables and water mains, may also sustain damage.

Widespread damage to roadside soils, vegetation, and trees has been attributed to liberal application of road salt. Sugar maples, especially in New England, have deteriorated extensively within a 5-year period. Leaf margin burn, limb dieback, and varying degrees of defoliation are noticeable even to an unobserving eye.

The EPA has initiated 4 projects in an attempt to better understand and control the road salt problem.

The first project was a study (1) that highlighted the need for more information on the effects of salt on the environment and man-made structures to allow accurate cost-benefit analyses of alternate approaches. Alternatives considered were pavement heating, a snowplow with compressed air, and a brush and blower system. Salting is still considered the most economical method of snow and ice control, but, as also suggested in the study, research is now under way to identify an inexpensive hydrophobic or icephobic (water or ice repellant) substance that would reduce ice adhesion when applied to the pavement (the second project). Economic analyses of salt damage and alternate methods are also being further explored (the third project).

The fourth project involved 3 independent projects. The first will determine by survey of best current practices the methods of optimum salt use. It will include an estimation of the minimum amount of deicing chemicals necessary for safe traffic flow under varying weather conditions, guidelines for application, and instrumentation and suggestions for legislation on salt use. The second aims at developing a practical guide for salt storage and handling. The third will examine the ecological effect of dumping large quantities of snow from streets and highways into water bodies or water supply watersheds. The chloride level will be monitored at several points and samples will be tested for nitrogen and nitrates, sodium, phosphorous, lead, mercury, chromium, oxygen demand, oil and grease, and various solids.

Together these projects will produce an accurate evaluation of the damage and associated costs of chemical deicing with respect to the environment, vehicles, and highway structures. Continued excessive use of salt will, of course, increase the damage; but high speeds, tight commuting schedules, public expectations, and highway department habits make a ban impractical.

Since it must be used for the present, salt should at least be used as efficiently and carefully as possible. Several state and local governments, including Minnesota, Vermont, and Massachusetts, have recognized this and through legislation have attempted to improve present practices. More research is needed in several fields to avoid the dangers that may result from a hasty, simplistic solution to this problem.

It would be good for us all to keep in mind a slogan of the Connecticut Highway Research Department: "Remember, if a little bit of salt is good, more is not necessarily better!"

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DISCUSSION

Richard Fenton, Environmental Protection Administration, City of New York

Those of us who have been trying to develop more solid basic data on the quantities of chemicals needed by operating personnel welcome the interest of the Environmental Protection Administration in this area of winter highway maintenance. Perhaps as a result of these EPA studies we can devise a cooperative research program and get answers to questions that have nagged us for decades.

With respect to the report itself, the most startling comment was that there is no conclusive evidence that the use of salt has made winter travel safer. I do not know what evidence would be considered conclusive. Anyone who has attempted to drive on packed snow or ice knows that it takes a longer distance to stop a car on such surfaces than on bare pavement. Braking distances on different surfaces are easily measured to determine how many additional feet are necessary to stop on ice or snow-covered surfaces versus bare pavement. It is not only the longer stopping distance that is troublesome, but also the fact that there is a loss of control. That a car may go sideways or in a direction other than a straight line is particularly vexing and dangerous. Thus, I believe it is only common sense for operating personnel who have the responsibility to make the roadways safe to strive for a bare pavement. It is the safest roadway condition.

Salt is a common substance, perhaps one of the commonest in continuous use from before recorded history to the present. In New York City, for example, we have been able to obtain it for many years in large quantities at a price of less than 1 cent per pound. There is not much else you can buy at that price. When there is an effective substance at that price level, operating officials will certainly want to examine carefully any suggestions for changes in procedures.

That rock salt, or almost any other substance that is effective on snow and ice, could cause some environmental damage if improperly used is not a surprising finding. Salt is common in our diets, but how many are aware that about 4 tablespoons is a lethal dose? I think the report does not recognize fully the problems faced by line supervisors, who must make the roadways passable as rapidly as possible so that people and goods move freely and winter storms cause a minimum adverse impact on a community's economy.

With respect to salt storage sites as sources of environmental damage, there is little excuse for that today. Present knowledge is adequate to isolate such piles from the environment.

With respect to anti-caking additives, particularly the ferrocyanides, these have been a substantial boon to highway salt users. A prudent operating agency, because of lower cost and easier delivery, would ordinarily purchase its salt in advance of the winter season and store it at strategic locations ready for use. Because the weather fluctuates, there have been times in New York City, for example, when we have had a relatively mild winter. This resulted in carrying over much of the stored salt for use during the following winter. Thus, it was not unusual to have salt stored for as long as 18 months before it was used. In pre-additive days, it was also typical for substantial caking to occur, requiring the use of pneumatic drills to break up the salt into large chunks before use. The large chunks of salt would then be crushed under the wheels or tread of a tractor before being loaded into a spreader. With that kind of operation, calibrating a salt spreader would, of course, become meaningless, since particle sizes were unknown and erratic.

In the early 1950s we began a series of storage tests in New York City, some on a large scale—using 100 tons of salt at a time in abandoned coal silos—and some on a smaller scale—using upended, large-diameter sewer pipe to simulate a silo. We tested the common anti-caking substances, such as cornstarch, silica gel, and 3 or 4 other substances. None worked when stored for a period of 24 months in covered vertical storage with good protection from the elements. Then, in cooperation with a major salt producer, we tested a ferrocyanide. It worked. The significance of vertical storage is that salt spreaders can be loaded rapidly by gravity when speed is important in fighting a snowstorm. Further, in urban areas, where real estate is expensive, vertical storage requires less land area than horizontal storage. About a dozen years ago, the ferrocyanides came into common use and revolutionized salt storage by virtually eliminating the caking of salt in covered storage. Thus, it made practical the use of calibrated spreaders, which made it, at least theoretically, possible to spread a predetermined quantity.

Certainly any potential side effects should be carefully studied, as suggested in the EPA report. I would like to add another comment in relation to such studies. Storm water from coastal cities along the eastern seaboard drains into the Atlantic Ocean. The potential problems for the urban coastal cities may be significantly different from those of inland communities.

With respect to effects on water supplies, the studies in Massachusetts I have seen that indicated a sharp rise in chloride levels seem to be relatively few in number and where the wells adjoined haphazard storage piles or were close to major highways. The general water supply in the snow belt should be monitored and the chloride data published periodically in journals usually read by public works officials so that all concerned may have ready access to the facts.

With respect to the corrosion of vehicles, we conducted such studies in the early 1950's in New York City. In these studies, plates made of the same steel as commonly used for auto bodies were fastened to the underside of city vehicles that operated in salt-free areas as well as in areas using salt. Some plates were also placed on the roofs of public buildings to determine how much corrosion might be attributed to atmospheric conditions. Our findings were that about one-half to two-thirds of the corrosion of the plates could be attributed to atmospheric conditions. These tests were done before undercoating was widely available and had become a common preventive measure adopted by many motorists.

With respect to damage to roadway surfaces, well over 90 percent of our surfaces are asphalt or are unpaved and thus are not affected by salt. It has been a requirement for many years that all exterior concrete in New York City be made with air-entrained concrete. Further, when our local building code was revised about 10 years ago, air-entrained concrete was made a requirement for the interior concrete floors of garages to eliminate damage from salt tracked in on tires.

With respect to underground utilities, it should be noted that naval architects have been designing for a saltwater environment for a long time. Perhaps those who have responsibilities for subsurface utility design should review what is done on shipboard to minimize corrosion. In some of the subsurface facilities we studied in New York City, we found that no provision had been made for the drainage of storm water. One of the local utilities relied on a truck-mounted pumper, which emptied the standing water about once a year. This was for installations that generated much subsurface heat, which no doubt evaporated much of the storm water. However, if any salt were present, obviously the salt solution would become more concentrated as the evaporation proceeded. In addition, all other things being equal, corrosion is greater as the temperature rises. For that kind of subsurface utility design, how much blame can be reasonably attributed to a public works agency using salt to make the roadways safe? Further, many of these utility installations were in the gutter areas where maximum inflow would occur rather than in the relatively sheltered sidewalk areas.

With respect to anti-corrosion additives, we also ran corrosion tests, using the aforementioned steel plates at the same time as the other tests were being conducted, in a test area where we used an additive. Our findings were that it was useless under our field conditions. Further, we found that the additive seemed to have a slight tendency to cake the salt somewhat more quickly than would otherwise occur.

Salts that are soft and that crush readily in handling create a high content of fine particles, and these are less desirable than salts that are harder and resist degradation: The more fines, the greater the tendency to cake. The marine salts are in the category of soft salts, and in past years we were reluctant to use them in New York City because of their poor storage characteristics, among other reasons. Further, it is apparent that spreading a predetermined quantity of the more easily degradable substances would be much more difficult than with the harder rock salt. In addition, the fines would dissolve on the surface of a thick layer of packed snow or ice, forming a slippery brine film that would diminish traction. Thus, a more dangerous condition would probably result than the original packed snow or ice.

With regard to the effects on soil and vegetation, in a congested urban community with paved streets and sidewalks there would be a minimum of observable effects.

With respect to the recommendations in the report, I would like to point out a few basic factors that face operating officials in coping with storms. To begin with, weather forecasting is still far from a precise science. In our city, there are sometimes substantial differences in depth of snowfall and temperature between one end of town and the other. In a storm where the average fall may be, say, 5 in., it would not be unusual to find variations of 2 to 3 in. in depth in locations several miles apart. Nor is it unusual to find sleet and icy rain in one part of town and just rain in another part, when the average temperature is at the freezing point. Thus, the amount of salt to be spread must be left to local supervisory discretion.

The temperature during a storm is critical in determining salt use, but so is the temperature immediately following the storm. If the forecast is for rising temperatures, then less salt would be needed than if the forecast is for falling temperatures. Since there is uncertainty in any forecast, the prudent public works official must make adequate allowances in the quantity of salt to be spread. Thus, I suggest that more accurate local forecasts are essential to a reduction in salt use.

The second basic problem faced by a public works official is how much salt should be spread. It may be a surprise to many that we do not have a very solid foundation of experimental data on which to base a judgment on the theoretical minimum amounts needed. Almost all of the studies I have reviewed are based on laboratory tests on ice in ice-cube-type trays. These ice-cube-tray experiments do not in my judgment completely simulate snow, which is a more elusive substance. However, ice-cube-tray tests are readily conducted and are easily reproducible, so they are quite convenient. However, we should bear in mind that ice is not snow and such tests do not have, among other things, warm automobile tires churning and mixing the snow and salt. If we are to determine the minimum salt needed, then there is an obvious need to conduct tests on snow with simulated traffic, as well as to bring in other relevant factors.

The third basic problem that confronts an operating official is to be able to spread on the roadways, with as much precision as possible, the minimum quantity that should be put there to provide a safe roadway. There are two subproblems involved here, as I see it. The first subproblem is to have salt of a uniform particle size distribution, so that we are dealing with the same substance in all snow operations, including the calibration of the spreaders. Unfortunately, this is not always possible. As noted earlier in relation to marine salts, rock salt, too, tends to form more and more fine particles as it is handled. Thus, the minimum amount of handling between the mine and the roadway would be necessary to ensure uniformity. If salt cakes in storage and has to be crushed in the maintenance yard before it can be put into a spreader, then the particle size distribution will be so variable that the calibrations of the spreaders would have no real significance. This is of major importance if environmental effects are to be minimized.

The second subproblem is to have reliable salt spreaders that can spread a predetermined quantity with due allowances for traffic conditions and other variables. It is encouraging that in the last quarter century of my personal observations there has been a decided improvement in equipment available for this purpose.

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We also welcome the interest of the EPA in this subject, and we are pleased to have this opportunity to comment on the EPA report.

The detrimental effect of salt additives is mentioned. One class of additives is the anti-caking agents such as ferric ferrocyanide, also known as Prussian blue, and sodium ferrocyanide, also known as yellow prussiate of soda. Salt for highway use is treated with 50 to 250 ppm of these additives. This is equivalent to 0.1 to 0.5 lb of anti-caking agent per ton of salt.

A few common items in which Prussian blue is used are household bluing, blueprints, blue-black ink, and carpenter's chalk. Sodium ferrocyanide is approved by the Food and Drug Administration (CFR 121.1032) as an anti-caking additive in table salt based on exhaustive tests wherein no evidence of toxicity was demonstrated at 500 ppm. Sodium ferrocyanide is therefore not toxic at any of the concentrations that would be encountered. Although laboratory work has shown that cyanide can be released from low levels of this compound by sunlight, no evidence has ever been found that would indicate that this phenomenon can occur under field conditions. Furthermore, this original laboratory research is being looked into more carefully, and a report is expected in the near future.

The report also names chromate and phosphate additives as being detrimental. We will not argue this point, but would like to state that these additives are no longer being used in highway salt.

It is true that highway salt can have a detrimental effect on roadside soils over a period of years. However, it has been shown that this effect can be reversed with gypsum (1).

We have conducted our own study regarding the chloride levels of water supplies throughout the United States and Canada. In Table 1 we find that the water supplies of cities selected at random have increased from 10.6 ppm chloride in 1947 to 17.7 ppm in 1971. Although this is a 66 percent increase, it is not serious when you consider that the Public Health Drinking Water Standards recommend a limit of 250 ppm chloride.

The chloride level of Lake Erie has also increased to 23 ppm. However, only 11 percent of this increase is attributed to deicing salts (2).

With regard to automobile corrosion, a report to be released by the National Association of Corrosion Engineers (3) states, "It has been widely quoted that corrosion damage devalues the automobile by about $100 annually. The widespread use of this number is regrettable because it is not derived on the basis of economic study. The $100 annual loss was simply estimated and should not have been construed in any way as being quantitative or semi-quantitative." Furthermore, comparison of trade-in values that appear in the publication by the NAD Used Car Guide Company shows that the annual difference in automobile values between the Northeast, where salt is used, and the Southeast, where it is almost never used, is approximately $4.50 per vehicle per year. Therefore, if there are other losses due to corrosion, these show up as repairs but do not affect trade-in values.

Many reports, including the EPA report, discuss the necessity for doing research on alternate deicing chemicals. Although there is always room for research, this subject has been thoroughly investigated (3, 4). With regard to alternates to chemical deicing, one report estimates that to install pavement heating on an Interstate highway would increase the construction costs by a factor of 8 (5).

With regard to underground utilities, the NACE Task Group Report (3) concludes: "Underground installations may suffer accelerated corrosion from salt brine seepage through the soil and through structural openings. Improved materials and coatings are being used extensively to mitigate underground corrosion."

Table 1.

Cities	Average Annual Chloride (ppm)					
	1947	1952	1957	1962	1967	1971
Atlanta, Georgia						1.0
Buffalo, New York				2.3	2.7	2.6
Chicago, Illinois	5.2	6.4	5.7	6.9	7.9	9.1
Cleveland, Ohio	20.0	20.1	20.6	24.0	27.2	23.5
Denver, Colorado	17.8	28.1	17.8	25.8	16.1	12.6
Detroit, Michigan	8	8	7	8	10	8
Hartford, Connecticut	2.4	2.4	2.4	3.4	5.0	6.0
Houston, Texas						
Indianapolis, Indiana	12	13	15	21	33	41
Los Angeles, California	31	26	31	28	27	28
Milwaukee, Wisconsin	4.3	5.0	5.6	6.8	8.0	8.5
Minneapolis, Minnesota	1.08	2.5	3.3	3.9	5.8	6.19
Montreal, Canada	14	20	22	24	25	28
New York, New York						
Oklahoma City, Oklahoma				117	111	112
Philadelphia, Pennsylvania				14.8	20.6	22.5
Phoenix, Arizona				146	121	181
Pittsburgh, Pennsylvania	25	23	25	23	21	19
Portland, Maine	1.5	1.5	2.5	2.5	4.3	3.5
Quebec, Canada	5	5	5	5	6	8
Rochester, New York			18.6	19.1	19.1	20.4
San Francisco, California	1.1		2.6	2.9	4.0	4.3
Seattle, Washington	2.7	0.6	1.8	2.2	2.4	4.4
Springfield, Massachusetts	1.6	1.8	2.1	5.8	13.6	17.0
Toronto, Canada	17.9	20.1	22.3	24.0	25.5	29.2
Washington, D.C.	5.0	3.78	7.0	10.0	10.9	11.9
Worcester, Massachusetts						
Average	10.6	11.7	12.3	14.0	15.6	17.7

The salt industry has often been accused of not making available full information on marine salts. If this situation has existed in the past, I am sure that it does not exist today among our members. This information is also available from other sources (6, 7).

The EPA report mentions an article by Feick, Horne, and Yeaple (8). We investigated this report and found that the soil was artificially contaminated with mercury (it contained approximately 2,900 ppm mercury versus approximately 150 ppm in the worst of naturally contaminated soils) and was treated with saturated brine (approximately 26 percent versus stream concentrations that would be in the parts per million range of chloride). These experiments were later repeated by the original authors using badly contaminated natural soils and brines up to saturation. It was found that mercury would not be released under these conditions, and the authors published their findings in the letters to the editor section of the July 13, 1973, issue of Science.

These comments are not given with the idea of being critical of the original EPA report but are for the purpose of supplying further information, some of which has been released quite recently or is in the process of being released.

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SOME COMPARISONS OF SOLAR AND ROCK SALT FOR ICE MELTING

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Limited field trials in New Hampshire provided motivation for some laboratory comparisons of solar, rock, and a 1:1 mixture of solar and rock salt for ice melting. The solar salt as received contained much larger particles than the rock salt. In this preliminary study, unsized samples were applied to trays of ice at 10 F in a cold chamber, and the ice melted and salt dissolved were measured as a function of time. During the first 3.5 hours, the cumulative ice melted did not vary significantly for the 3 test materials, but the solar salt melted more ice per unit weight of salt dissolved than the other 2 materials. Failure of solar salt to melt more ice than rock salt during the first hour was contrary to prior road trials. To test the possibility that this difference was due to the absence of particle size reduction by traffic in the laboratory tests, 2 size ranges of solar salt were compared for melting effectiveness. Small crystals melted twice as much ice as large crystals during the first 15 minutes, but the large crystals melted more ice per unit of salt dissolved. Fine solar salt mixed with coarse rock salt might give rapid melting and long-lasting effectiveness on highways.

•THIS report represents a preliminary laboratory investigation of 3 specific materials. To further validate the results, extensive field trials under controlled conditions will be required and a comprehensive literature investigation must be performed. Nonetheless, it is felt that the data may be of interest to many who are concerned with this problem.

EXPERIMENTAL DESIGN

A rack was constructed to accommodate three 11 × 17 in. (280 × 430 mm) trays [one over the other with an approximately 4-in. (100-mm) separation] in a temperature-programmable cold chamber. The trays were arranged so there was an incline of approximately 8 degrees (0.14 rad). Holes were punched in the lower edge of the trays to allow salt solution to escape continuously. The solution dripped into a trough and thence into a weighed collection vessel.

The holes were temporarily sealed and water was frozen in the trays to a depth of ¾ in. (19 mm) and left in a freezer overnight. Before starting a series of trials, trays were placed in the cold chamber for 1 hour at 10 F (-12 C) to allow the chamber to come to an approximate moisture equilibrium. A trial was started by placing 100 grams of salt in a band about 2 in. (50 mm) wide along a 17-in. (430-mm) length of the tray at the upper edge of the incline. As the ice melted, water could run to the lower perforated edge and escape.

It was known that the temperature and air flow patterns varied somewhat within the chamber. To eliminate these variables from the data, 3 trials were run with 3 trays in place each time. In any given trial, 1 tray had solar salt, 1 had rock salt, and 1 had a 1:1 mixture. Positions were shifted so that each salt was tested 1 time in each

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of the 3 chamber locations, i.e., top, center, and bottom. No salt particle size selection was employed, but, for the material submitted, the rock salt was somewhat finer than the solar salt. The experimental plan can be represented by the following array:

Position	Trial 1	Trial 2	Trial 3
Top	Solar	Rock	Mixture
Center	Rock	Mixture	Solar
Bottom	Mixture	Solar	Rock

RESULTS

The data in Table 1 represent the total salt dissolved and the total ice melted in the 3 locations of the chamber. The data confirm the suspicion that the top of the chamber is warmer than the center and bottom because more ice melted in the top position than elsewhere. It is perhaps surprising that the least ice melted in the center rather than at the bottom of the chamber. This can be explained by examining the pattern of air circulation. Actually, it is probably colder and there is less evaporation in the center because the air in that area is more nearly static. This is reflected by the higher ratio of ice melted per gram of salt dissolved in the center compared to both top and bottom (Table 1). Evaporation losses during collection of salt solution would reduce the estimate of ice melted.

In Table 2 are given the total weights of ice melted and salt dissolved for several time intervals up to a total of 6 hours. Each datum is the sum of 3 measurements on 3 separate trays—1 from each of the 3 positions in the chamber. Since each trial had 1 sample of each type of salt, all differences must be due to salt differences and experimental error. The first measurements were taken after 60 minutes because some time is required for the first runoff to occur. Thereafter, measurements were made every 30 minutes. The data in Table 2 do not show differences clearly due to random variations for short time intervals.

To facilitate detection of any meaningful differences, the data were recalculated in the form of cumulative results from initiation of the tests. These numbers are given in Table 3 and are shown in Figures 1 and 2. Figure 1 shows that considerably less solar salt dissolved than rock salt or the 1:1 solar-rock mixture over the 6-hour period. However, there was no meaningful difference in salt dissolved during the first hour. With respect to ice melted, differences during the first 3.5 hours were very small and probably not significant. After 3.5 hours, it is apparent that the mixture was more effective than either the solar or rock salt alone. This difference was probably caused by the large crystals of solar salt that were sitting on top of smaller crystals of rock and solar salt during the first half of the tests. The rock salt contained very few crystals with effective diameters (longest dimension) larger than 0.25 in. (6.3 mm), whereas some of the solar salt crystals were larger than 0.50 in. (12.7 mm). More will be offered on this point later.

It is also instructive to refer to Figure 2, where the ratio of ice melted to salt used is plotted. Here, it is apparent that solar salt melted more ice per unit weight of salt dissolved. As expected, the 1:1 mixture was intermediate in its efficiency, although it started out poorly.

In attempting to explain these results, it is important to recall that there was still at least 1 major difference between these tests and road conditions. In these laboratory tests there was no disturbance of the salt after it was applied (except runoff); that is, there was no traffic to cause crushing of crystals, etc. Somewhat faster initial melting was expected for solar than for rock salt, but this was not observed. One reasonable explanation for this anomaly was the larger mean particle size for the solar salt relative to the rock salt. A larger diameter would mean less surface area to contact ice and therefore slower melting. Although this particle size difference is not unusual, solar salt seems to work faster on the road, in the opinion of users. The most logical explanation for this difference is that solar salt, with a lower density than rock salt because it is not formed under high pressure, will crush to fine particles more quickly than rock salt under normal traffic conditions.

Table 1. Comparison of melting for 3 locations in cold box at 10 F.

Location in Cold Box	Sum of Three 6-Hour Tests: Total Salt Dissolved (g)	Total Ice Melted (g)	Ratio of Ice Melted to Salt Dissolved
Top	229.2	936.8	4.09
Center	193.4	804.8	4.16
Bottom	209.7	856.5	4.08

Table 2. Melting efficiency of solar, rock, and mixed salts at 10 F by time interval.

Time Interval Relative to Start (minutes)	Salt Dissolved During Time Interval Shown (g)			Ice Melted During Time Interval Shown (g)			Ratio of Ice Melted to Salt Dissolved During Time Shown		
	Solar	Rock	Mixed	Solar	Rock	Mixed	Solar	Rock	Mixed
0-60	25.2	27.7	26.6	109.0	94.5	80.6	4.33	3.41	3.03
60-90	26.8	28.5	25.6	99.6	109.5	104.3	3.72	3.84	4.07
90-120	25.6	27.1	26.7	109.9	117.1	113.7	4.29	4.32	4.26
120-150	21.5	32.7	29.8	93.8	97.9	110.1	4.36	2.99	3.69
150-180	20.3	24.3	23.1	101.8	96.9	103.2	5.01	3.99	4.48
180-210	17.4	16.8	22.6	87.0	70.0	92.5	5.00	4.17	4.09
210-240	17.6	14.8	19.1	69.1	77.2	87.3	3.93	5.22	4.57
240-270	13.4	14.6	17.0	53.9	54.5	72.3	4.02	3.73	4.25
270-300	13.2	13.5	15.5	62.5	48.7	73.7	4.73	3.61	4.75
300-330	4.5	8.9	10.6	28.2	30.6	45.0	6.27	3.44	4.25
330-360	5.3	6.4	9.6	27.7	33.3	42.7	5.23	5.20	4.45

Table 3. Melting efficiency of solar, rock, and mixed salts at 10 F by cumulative weight.

Cumulative Time (minutes)	Cumulative Weight of Salt Dissolved (g)			Cumulative Weight of Ice Melted (g)			Ratio of Cumulative Weights of Ice Melted to Salt Dissolved		
	Solar	Rock	Mixed	Solar	Rock	Mixed	Solar	Rock	Mixed
60	25.2	27.7	26.6	109.0	94.5	80.6	4.33	3.41	3.03
90	52.0	56.2	52.2	208.6	204.0	184.9	4.01	3.63	3.54
120	77.6	83.3	78.9	318.5	321.1	298.6	4.10	3.85	3.78
150	99.1	116.0	108.7	412.3	419.0	408.7	4.16	3.61	3.76
180	119.4	140.3	131.8	514.1	515.9	511.9	4.31	3.68	3.88
210	136.8	157.1	154.4	601.1	585.9	604.4	4.39	3.73	3.91
240	154.4	171.9	173.5	670.2	663.1	691.7	4.34	3.86	3.99
270	167.8	186.5	190.5	724.1	717.6	764.0	4.32	3.85	4.01
300	181.0	200.0	206.0	786.6	766.3	837.7	4.35	3.83	4.07
330	185.5	208.9	216.6	814.8	796.9	882.7	4.39	3.81	4.08
360	190.8	215.3	226.2	842.5	830.2	925.4	4.42	3.86	4.09

Figure 1. Rate of melting in a 10 F chamber.

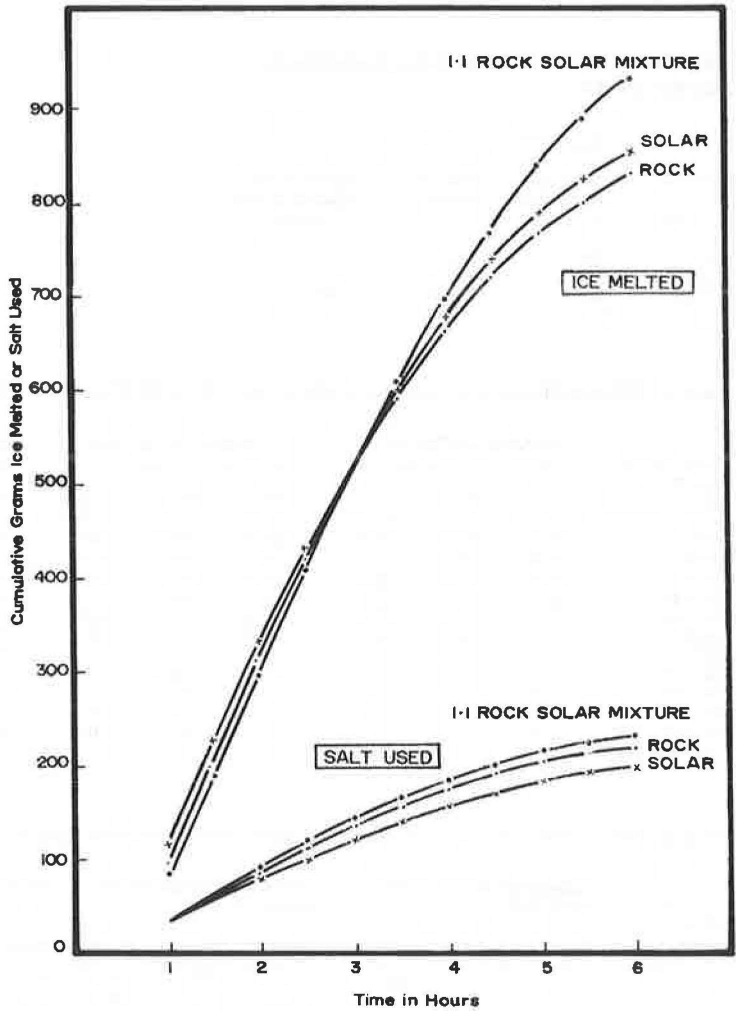
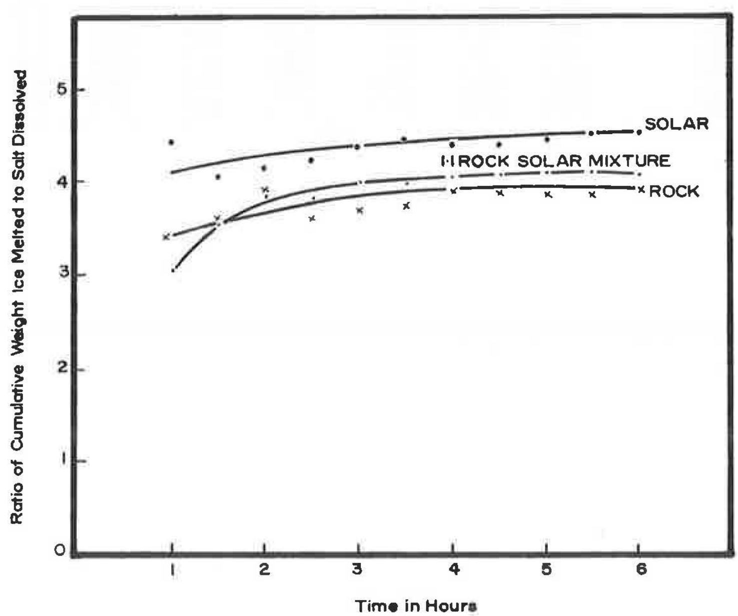


Figure 2. Melting efficiency of different salts in a 10 F chamber.



To test this hypothesis, 5 replicate samples of both solar and rock salt were prepared for compression tests. To eliminate particle size differences, all material was screened to smaller than No. 4, larger than No. 8 mesh. Samples (approximately 100 g) were loosely packed in a cup to a depth of 1 in. (25 mm), and the pressure required to compress it to ¾ in. (19 mm) during 1 minute was measured. The data are given in Table 4. In view of the empirical nature of this test and difficulty of uniformly packing the samples, it is not surprising that there is considerable variation. Still, a statistical test applied to the means indicates a difference in compressive strength at the 85 percent probability level. It seems reasonable to conclude that solar salt does crush more readily than rock salt.

It now remained to demonstrate that fine particles of solar salt will melt ice faster than larger particles of solar salt. For this test, duplicate 100-g samples were prepared in 2 different size ranges: 0.500 to 0.375 in. (12.7 to 9.5 mm) and 0.187 to 0.094 in. (4.7 to 2.4 mm) for the longest dimension. Two tests were run in the cold box using the 11 × 17 in. trays as before. In the first trial, the fine crystals were at the top of the chamber and coarse ones at the bottom. For the second trial, positions were reversed to compensate for temperature differences. To speed up the measurement process and to make it possible to get data shortly after the start of a trial, the average temperature in the cold box was raised to 27 F (-3 C).

The results are given in Tables 5 and 6 and are shown in Figures 3 and 4. The first point to note is that the small crystals melt more ice (on an absolute basis) than the large crystals throughout the trial. This is shown in Figure 3 and also in Figure 4 in the bottom curve where the ratio of ice melted by the 2 sizes of crystals is plotted. It is noteworthy that this higher melting efficiency for the small crystals is most strongly manifested at the start of the trial. During the first 15 minutes after application, the small crystals melted twice as much ice as the large crystals. This fact, coupled with the relative ease of crushing of solar salt, probably accounts for its very fast action in road tests.

Another fact shown by the data is that the small crystals dissolve much faster and therefore would not be as long-lasting in road use. Further, the fast rate of runoff associated with the use of small crystals produces a lower "total capacity for melting". This is shown in the 2 top curves of Figure 4, where the large crystals consistently melt more ice per gram of salt dissolved. In other words, large crystals melt more ice per unit of weight than small crystals, but they dissolve much slower and therefore actually melt much less ice during the first hour or so after application. The resistance of rock salt to crushing, with attendant reduction in particle size, probably partly explains why it is longer lasting than solar salt during normal road use.

The last point to be made concerns the much higher quantity of ice melted per gram of salt used in the last tests compared to the earlier ones. This is explained by the fact that the temperature in the last tests was 27 F (-3 C) and in the first tests it was 10 F (-12 C). Runoff occurs with a more dilute solution as the temperature is raised. However, it is clear that large applications of salt can produce melting and runoff at 10 F (-12 C). Further, it is likely that the use of small particles of solar salt would provide much-improved melting compared to unsized solar or rock salt when the temperature is below 15 F (-9 C).

SUMMARY

1. The compressive strength of solar salt is less than that of rock salt; that is, solar salt is crushed more easily. It is likely that traffic reduces solar salt to fine particles faster than rock salt.

2. Comparison of large solar salt particles (0.500 to 0.375 in. diameter) with smaller solar salt particles (0.187 to 0.094 in. diameter) showed that (a) small particles melt ice much faster than large particles immediately after salt application, but the difference decreases continuously over a 2-hour test period—for example, during the first 15 minutes, the small crystals melted twice as much ice as the large crystals, but between 105 and 120 minutes after the start, the small crystals only melted 1.1 times as much as the large crystals; (b) the small crystals also dissolved much faster and therefore

Table 4. Comparison of crush strength of solar and rock salt.

Trial	Load (lb) Required to Compress From 1 in. to ¾ in. Solar	Rock
1	3,400	5,130
2	4,880	5,400
3	4,750	5,000
4	5,020	4,180
5	4,000	5,400
Means[a]	4,410	5,020

[a]A statistical comparison of the means shows that the average load required to compress the rock salt was higher than that for the solar salt at the 85 percent probability level.

Table 5. Melting efficiency of 2 sizes of solar salt crystals at 27 F by time interval.

Time Interval Relative to Start (minutes)	Salt Dissolved During Time Interval Shown (g)		Ice Melted During Time Interval Shown (g)		Ratio of Ice Melted to Salt Dissolved	
	Large Crystals	Small Crystals	Large Crystals	Small Crystals	Large Crystals	Small Crystals
0-15	5.6	15.5	43.9	87.2	7.84	5.63
15-30	12.6	20.0	88.4	118.9	7.02	5.95
30-45	13.4	23.3	86.4	115.4	6.45	4.96
45-60	12.9	26.7	86.6	111.2	6.71	4.16
60-75	13.1	21.1	77.9	108.2	5.95	5.13
75-90	12.9	18.0	86.9	99.4	6.74	5.52
90-105	12.8	14.2	79.4	77.3	6.20	5.44
105-120	9.5	12.0	61.2	68.8	6.44	5.73

Table 6. Melting efficiency of 2 sizes of solar salt crystals at 27 F by cumulative weight.

Time Interval Relative to Start (minutes)	Cumulative Weight of Salt Dissolved From Start (g)		Cumulative Weight of Ice Melted From Start (g)		Ratio of Cumulative Weights of Ice to Salt	
	Large Crystals	Small Crystals	Large Crystals	Small Crystals	Large Crystals	Small Crystals
0-15	5.6	15.5	43.9	87.2	7.84	5.63
15-30	18.2	35.5	132.3	206.1	7.27	5.81
30-45	31.6	58.8	218.7	321.5	6.92	5.47
45-60	44.5	85.5	305.3	432.7	6.86	5.06
60-75	57.6	106.6	383.2	540.9	6.65	5.08
75-90	70.5	124.6	470.1	640.3	6.66	5.14
90-105	83.3	138.8	549.5	717.6	6.60	5.17
105-120	92.8	150.8	610.7	786.4	6.58	5.21

Figure 3. Comparison of melting rates and salt use for large and small solar salt crystals in a 27 F chamber.

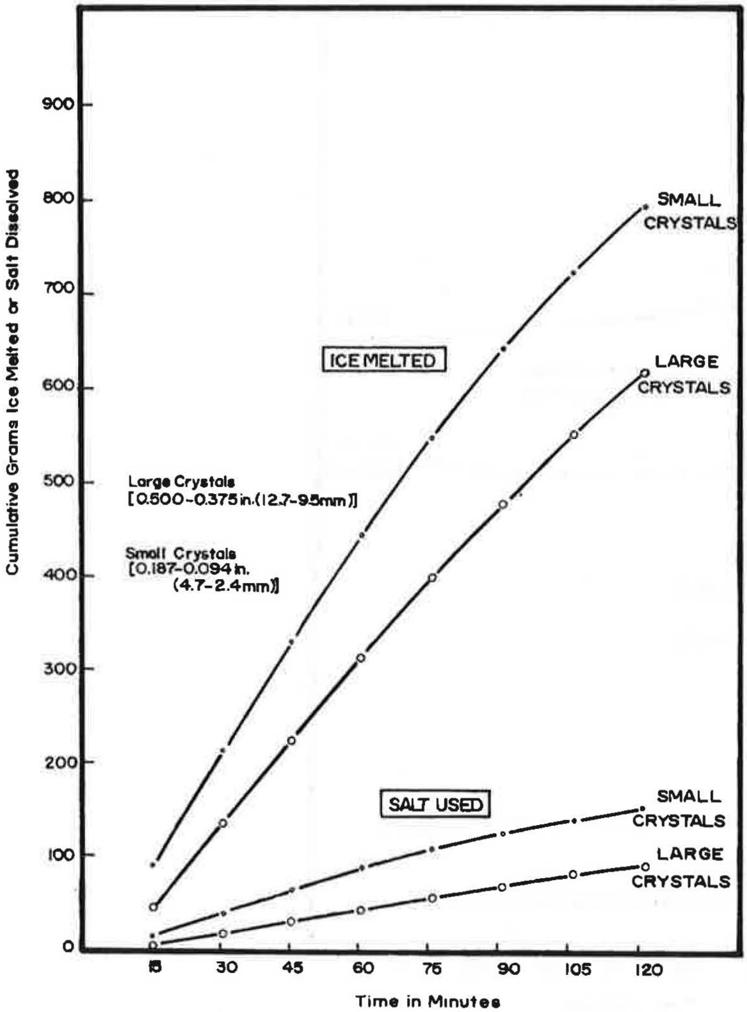
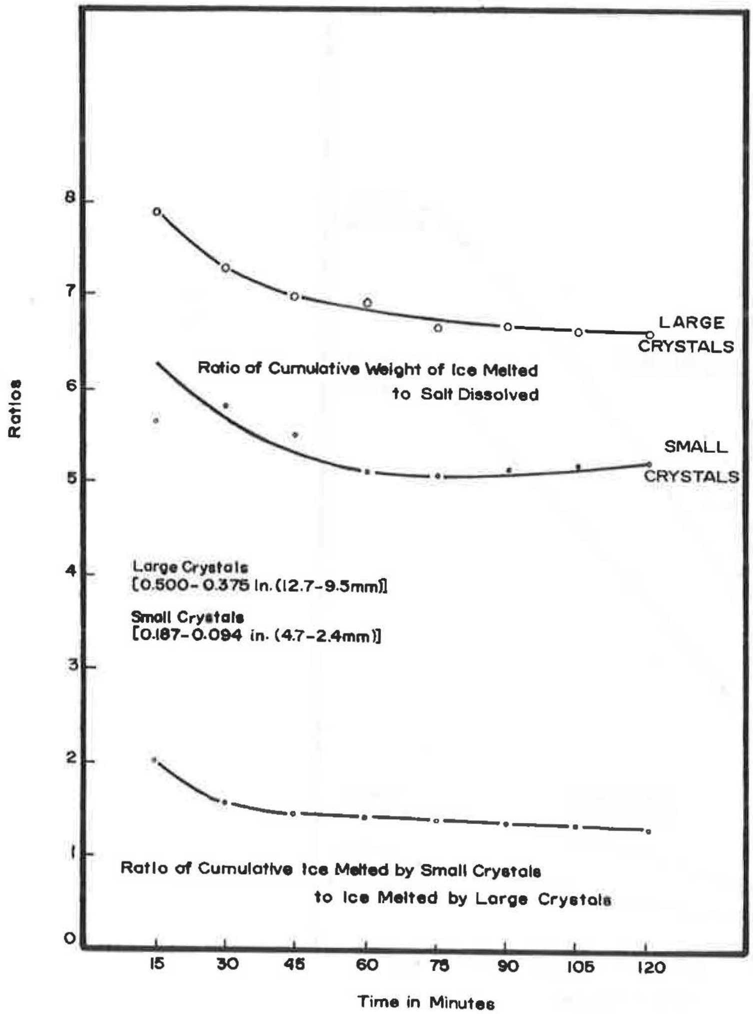


Figure 4. Comparison of melting efficiency for large and small crystals of solar salt in a 27 F chamber.



would not last as long in normal road use; and (c) the fast rate of runoff associated with the small crystals produces a lower "total capacity for melting"—i.e., small crystals melt less ice per unit weight of salt than large crystals.

3. Because large crystals melt more total ice than small crystals but small crystals produce faster initial melting, it appears probable that a mixture of normal-sized solar and rock salt should, under road conditions, produce both fast initial action and long-lasting action. This conclusion is justified by the fact that traffic should break the solar salt into rather fine particles quite quickly but will not reduce the rock salt size as quickly.

4. A 6-hour test at 10 F (-12 C) was conducted to compare rock salt, solar salt, and mixed (1:1) rock and solar salt under static conditions; that is, the salt was not disturbed after application and therefore there was no crushing action as in normal road use, and we would not expect fast melting action. As expected, there was little difference in the amount of ice melted during the first 3.5 hours; but between 3.5 and 6 hours, the rock and solar salt mixture melted 50 percent more ice than either rock or solar salt alone.

5. For these same conditions, solar salt melted more ice per unit weight of salt dissolved, the 1:1 mixture was intermediate, and the rock salt melted the least ice per gram of salt used. This was probably because the mean particle size of the solar salt was larger than that of the rock salt.

6. Because solar salt crushes readily, its use would be advantageous for severe temperature conditions, such as 10 to 15 F (-12 to -9 C).

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DISCUSSION

Frank O. Wood, Salt Institute, Alexandria, Virginia

In work of this type performed for us, we have found that the location of the trays in a ventilated cold room is most important, and we are pleased to see that researchers at the University of New Hampshire considered this variable in their investigation.

The purpose of the tests performed for us was to determine the effect of particle size on melting rates, and therefore each of the components of the screened fractions was weighed out for each test in order to control this parameter. However, 5-g samples were used. Therefore, a slight error in sampling could have made a considerable difference in the results, whereas the University of New Hampshire was using 100-g samples. We would recommend that salt meeting the latest ASTM D-632 specification be used.

We believe that a better case could have been made for the solar salt and rock and solar salt mixtures under the influence of traffic if the degradation in terms of screen size had been determined for these salts crushed between a hard surface and original-equipment rubber tires with 1,085-lb loading and assuming a reasonable vehicle count for a reasonable melting period. These screen fractions could then have been weighed out and used to make a direct measurement of the melting rate.

We considered cumulative ice melted as the most important measurement in tests run for us. Actually, readings in our tests were taken on the runoff solution after 15, 30, 60, 90, and 120 minutes. Readings taken after 90 minutes were not considered significant. Significant differences in ranking were found when running these tests at 9, 18, and 28 F (-13, -8, and -2 C).

We fully realize that research of this type at this stage of development is subject to opinion. We trust that the work done by the University of New Hampshire, plus our comments, will increase the body of knowledge with regard to these techniques.

FURTHER EVALUATION OF DEICING CHEMICALS

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Severe corrosion of reinforcing steel and deterioration of concrete in reinforced concrete bridge decks caused by salt applied to the decks to control ice and snow have prompted a search for a noncorrosive deicing chemical suitable for maintenance use. Seventeen candidate chemicals have been evaluated. Tetrapotassium pyrophosphate exhibited good frost-preventing properties, and 2 years of limited field testing on bridge decks is reported. A skidding-car method of determining coefficient of friction is evaluated. The results of sodium formate used as a deicer and its detrimental effect on concrete are noted.

•CONSIDERABLE attention (1, 3, 4, 5, 11) has been given to the problem of bridge deck deterioration. In general, the results have shown that one of the most significant causes of rusting of the steel and spalling of the concrete is the use of salt for snow, ice, and frost control on bridge decks. In this respect, studies have been made to determine the feasibility of (a) the heating of bridge decks, thus reducing or eliminating the need for salt to prevent frosting or icing; (b) the use of waterproof membranes so that salt is prevented from coming in contact with the concrete; (c) the use of polymers or other penetration-type sealers to make concrete itself sufficiently waterproof so that chlorides may not be able to penetrate the concrete in a short time; and (d) the use of chemicals other than chlorides that not only will control ice and frost but also will be noncorrosive to either the steel embedded in the concrete or the concrete itself (2, 6, 7, 8, 9).

In a previous study, 17 different potential deicing chemicals were subjected to various laboratory and field tests (11). Of these 17 chemicals, only sodium formate and tetrapotassium pyrophosphate were found to be reasonably effective alternative deicing chemicals and yet not any more toxic or ecologically harmful than sodium chloride.

As a result of laboratory studies, tetrapotassium pyrophosphate (TKPP) was tested by highway maintenance forces at selected bridge locations. These bridges were "salted" to prevent frosting and not for the purpose of snow and ice removal. Because TKPP costs about 15 times as much as salt, its use was considered most appropriate for those locations where only the bridge deck is "salted".

Initially the work was oriented primarily toward a laboratory search for alternative deicing chemicals, with research personnel performing a minimum field evaluation to confirm the test results. This report presents the results of the use of the chemicals by maintenance personnel to determine if there were any operational difficulties. This report is the finalization of the original project. It gives the results of 2 years of field testing at selected locations, along with further evaluations of skid resistance and corrosion.

LABORATORY TEST DETAILS

PCC Durability

In order to determine to what degree the various deicing chemicals could adversely affect concrete, 84 portland cement concrete cylinders ($4\frac{1}{2} \times 9$ in.) with embedded gauge

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plugs at each end were subjected to alternate immersion tests. Changes in length and observations of physical distress were noted. The cylinders were made from 2 mix designs; one had 4½ sacks of cement per cubic yard at 2¾-in. slump and 5.8 percent entrained air, and the other had 7 sacks of cement per cubic yard at 4-in. slump with 4.5 percent entrained air. All cylinders were cured for a minimum of 28 days by complete immersion in tap water at room temperature, then oven-dried at 140 F for 28 days in a forced-draft oven. In one series the specimens were alternately completely immersed in the solutions for 7 days followed by oven-drying 7 days at 140 F. Changes in length and weight were measured and visual distress was noted after each cycle. In a second series, other specimens were continually partially immersed (2 in.) in the solutions with no oven-drying. Figure 1 shows the results of alternate immersion and oven-drying on length change for each of the solutions used. The following is a summary of these tests.

1. Both 4½- and 7-sack concrete cylinders were not significantly affected after 41 cycles of wet-dry tests when alternately submerged in tap water.
2. Concrete cylinders cycled and fully submerged in a saturated sodium chloride solution were first observed to have scaling of the surfaces of all cylinders after the third cycle. A progressive deterioration of the surface continued for approximately 80 cycles. After 80 cycles, the deterioration was so severe that the test was discontinued. Typical deterioration of the 7-sack concrete that was alternately immersed in the sodium chloride solution is shown in Figure 2.
3. After 25 cycles in a 60 percent solution of TKPP, no deterioration was evident on either the 4½- or 7-sack concrete cylinders.
4. After 25 cycles in a saturated urea solution, only negligible surface scaling was observed on the 4½- and 7-sack concrete cylinders.
5. No adverse effect was noted on the cylinders that were partially immersed in tap water, saturated sodium formate, or saturated sodium chloride.
6. After 3 cycles of complete immersion and oven-drying in the sodium formate solution, the 7-sack concrete exhibited severe distress (Figure 3).

Sodium Formate and Asphalt Concrete

Asphalt concrete briquets were cycled between 7 days of immersion in a saturated sodium formate solution and 7 days of drying in a 140 F oven. One sample that was made up of approximately a 1¼-in. thick layer of asphalt concrete on top of a 1-ft square concrete block was also cycled. After 5 alternate wet and dry cycles, no serious deterioration occurred in the asphalt surfacing or briquets. There did not appear to be any loss of bond between the asphalt concrete and the concrete block. There was, however, severe deterioration of the exposed surface of the 1-ft square concrete block.

Effect of TKPP on Glass and on Asphalt Concrete

Preliminary tests on automobile windshield glass indicate that 30 percent solution of TKPP (with a corrosion inhibitor of sodium metasilicate) had no effect on the tested glass.

A limited test on asphalt concrete briquets that were cycled between immersion in a 60 percent TKPP solution and drying in a 140 F oven showed no apparent undesirable effects.

TKPP and the Corrosion of Steel

Steel immersed in a 5 percent solution of TKPP with a corrosion inhibitor consisting of 2 percent sodium metasilicate results in an insignificant corrosion rate of 0.053 mils per year. A 3 percent sodium chloride solution resulted in a corrosion rate of approximately 4 mils per year, and in distilled water the steel corroded at a rate of 6 mils per year.

It should be pointed out that TKPP is apparently not readily absorbed by concrete. Therefore, the corrosivity of this chemical to steel would probably be limited to bare steel on spray equipment or vehicles.

Figure 1. Elongation plot for concrete cylinders cycled in various saturated solutions.

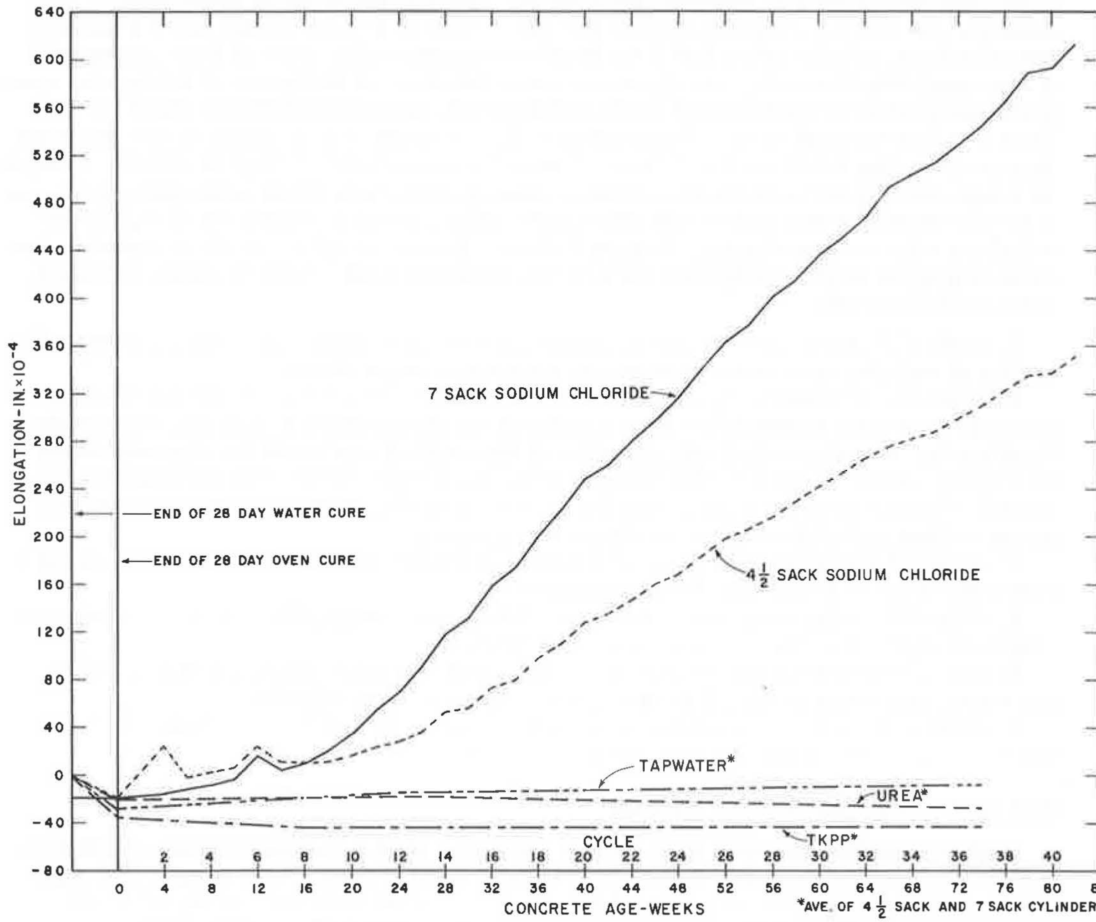

Figure 2. Concrete cylinders after 40 cycles in a sodium chloride solution.

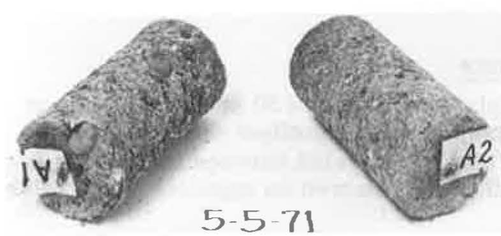

Figure 3. Appearance of concrete after 3 cycles of exposure to sodium formate.

FIELD TRIAL OF TETRAPOTASSIUM PYROPHOSPHATE

The chemical TKPP underwent field trials during the winters of 1971 and 1972 in 7 geographic areas of California. The test areas included locations where only the bridge decks would become frosty and there was no snowfall and other areas where heavy snow and icing occurred. In the latter locations, TKPP was not effective in this test series because of the low temperatures encountered (below 25 F).

The following is a summary of the observations concerning the effectivness of TKPP in the various locations.

1. Russian River, Bridge 10-182, elevation 710 ft—TKPP was applied at a rate of 0.01 lb/ft^2 of deck and remained in place for 15 days. No frost occurred after application at this location. The chemical appeared to be "available" because there was evidence of formation of TKPP crystals upon evaporation of the water, and the pavement appeared wet in the early morning due to the deliquescent effect of the chemical. No evidence of pavement slipperiness was noted. A "wet" appearance of the deck has been evidence that TKPP has prevented or controlled frosting.

2. Grass Valley Creek, Bridge 5-10, PCC deck, elevation 2,200 ft, and Bridge 5-13, AC overlay, elevation 2,110 ft—A spray solution of 30 percent TKPP was applied at a rate of 0.01 lb/ft^2. Two days after the application, frost conditions were present as the temperature reached 27 F and the relative humidity was about 100 percent. The decks did not frost over; however, they were wet due to the deliquescent effect of the chemical. On both of these structures, at a later date, the TKPP powder was applied in conjunction with 1½ yd^3 of sand. The wet sand froze to the bridge decks.

For these same decks, the normal application of chemical solution was applied and was reported to be effective for a period of 7 days because of the early morning wet-appearing decks. A second application of the chemical was made, and 3 days later the temperature was 22 F and frost was observed on the ground adjacent to the bridges. The bridges at this time were frost-free but wet-appearing. No pavement slipperiness was observed.

On Bridge 5-10, the average skid distance on dry pavement was 4.5 ft, while on wet pavement containing TKPP the average distance was 4.8 ft. On Bridge 5-13, the average skid distance was 3.5 ft on dry pavement and 4.5 ft on wet pavement containing TKPP.

3. Sacramento Weir, Bridge 22-32 with overlay—A 30 percent solution of TKPP was applied at a rate of 0.01 lb/ft^2 of deck surface. Immediately after applying the chemical, it was found that a pickup truck could quickly stop on the bridge. However, within 10 minutes after applying the chemical, a light application of sand was placed on the bridge deck. The sand caused the pickup truck to slide on the bridge deck when the brakes were applied. As soon as traffic whipped the sand from the traveled way, the deck was no longer slippery. Sand was not reapplied with the deicing chemical at this location.

Two days after the application of the chemical, the bridge was under frost conditions as the temperature was 29 F and frost was observed on the guardrails. The bridge deck had a wet appearance. It was necessary to salt and sand nearby bridges. At one time on this bridge, 1 day after the application of the chemical, the maintenance foreman reported that the pavement was slippery when the pavement appeared wet. The early morning temperature was about 27 F. It is possible that the chemical was too heavily applied when considering the residual chemical that was still in place on the deck. It was effective in preventing frost during frost conditions on this deck for a maximum period of 12 days when there was no rainfall.

4. Wheatland, Bear River Bridge, PCC deck, elevation 108 ft—One standard application of chemical was observed to be effective on this bridge for an estimated period of 19 days. Even though this bridge showed evidence of frost on the rails but not on the deck, during this time period another bridge about 7 miles away received 20 applications of salt and sand. This bridge had an average skid number SN_{40} of 46, while the skid distance on the dry deck was 4.8 ft. When wet with plain water the average distance was 6.4 ft, and when wet with a TKPP solution the average distance was 6.3 ft.

5. Hemet Valley Creek, Bridge 56-184, AC overlay, elevation 4,360 ft—One standard application of chemical was placed on this bridge deck at time intervals of 6, 9, and 7 days. During this period, the deck had a wet appearance in the early morning, with no

frost present on the deck. The minimum morning temperature was about 24 F for an estimated 4 days. Adjacent bridges required salt and sand for frost prevention. No slipperiness of the deck was observed by the maintenance personnel.

6. Bradley Overhead, Bridge 39-44, District 10, AC overlay, elevation 170 ft—TKPP was applied and thought to cause slipperiness. Use of the chemical was discontinued.

7. Sutter County, G. S. Housely Bridge, corrugated steel plank deck with AC riding surface—The bridge is a county-owned bridge that does not normally receive deicing chemicals. Therefore, TKPP was applied only to the northbound lane and the southbound lane was left untreated as a control. The typical method of applying the chemical is shown in Figure 4.

Two days after TKPP solution was applied, the southbound lane was frosty (no chemical) while the treated northbound lane was frost-free but wet. The air temperature was 29 F and the relative humidity was 90 percent. The typical appearance of this bridge during the test is shown in Figure 5.

The structure was maintained in a frost-free condition during the entire test period. The early morning temperatures did not fall below about 24 F.

The effect of using the chemical on the skid resistance of this deck surface is given in Table 1 for AC overlaid bridge deck.

A few trial skid tests using the skidding-car test were made on the frosty side of this bridge. It was found that there was no significant difference in the skid distance between the frosty or wet bridge deck. However, this would not be true if the deck were icy or had a layer of snow. In this case, the frost apparently caused little danger to traffic as far as skidding was concerned.

FIELD SKID TESTING

Towed-trailer skid tests were performed using solutions of sodium chloride, TKPP, and urea on both concrete and asphalt pavements. Work with the towed skid test trailer (ASTM test method E 274-65T) showed that this method was not applicable for evaluating the effects of different solutions on pavement friction. This was because the test method requires the application of water, which overshadows the presence of the chemical. A skidding-car method was determined to be the best test available to maintenance superintendents for evaluating the effects of the solutions on pavement surfaces (10). Theoretical analysis and field tests suggest that if a vehicle that is traveling at 10 mph can stop in less than 8 ft of locked-wheel braking, the pavement can be regarded as not being slippery. Limited test results using the skidding-car method indicate that individual applications of up to 0.01 lb/ft^2 of 30 percent TKPP solution will not significantly affect the slipperiness of the roadway. However, much depends on the surface texture of the pavement, because even plain water can be a hazard with a smooth pavement.

Initially, the field tests of the TKPP solution encompassed the application of sand at the same time. It was found that the sand application itself caused the deck to be "slippery" and this operation was discontinued. Apparently sand is effective for packed snow and ice but not necessarily satisfactory for wet or frosty conditions except as a "blotter".

Because the commonly used skid testing devices did not show the true effect of the chemical, it was decided to try the skidding car method (10). This method consists of measuring the length of skid of a standard sedan with locked wheels. The automobile was equipped with a powder-actuated marking device connected to the brake pedal. The test speed used was 10 mph. The distance between a chalk mark on the pavement occurring at the instant of wheel lock and another one made after stopping is the measure of skid resistance. The specially mounted speedometer used to more easily control the test speed is shown in Figure 6; Figure 7 shows the special marking devices mounted on the automobile bumper.

After several trials, it was decided that a "go, no-go" test result for the effect of the deicing chemical on the pavement should be used. The criteria for the test were that the application of the chemical should not cause a serious degradation of the coefficient of friction of the pavement surface and the maximum average stopping distance

Figure 4. Application of 30 percent solution of TKPP.

Figure 5. Sutter County test bridge: 30 percent TKPP has been applied to right side of bridge; note frost on left side.

Table 1. Results of skid tests.

	Average Skid Distance (ft)[a]			
Bridge Deck	Dry	Wet (Water)[b]	Wet (Chemical)[c]	Wet (Chemical-Humidity)[d]
PCC	4.7 (13 tests)	6.3 (8 tests)	6.3 (20 tests)	6.6 (2 tests)
AC overlaid	5.4	5.7	6.8	7.1

[a]Braking distance when vehicle velocity is 10 mph.
[b]Sprayed to have continuous film of water.
[c]Immediately after applying 0.01 lb/ft^2 of TKPP.
[d]Deliquescent effect of chemical in producing a wet deck during high humidity.

Figure 6. Special speedometer mounted adjacent to the steering wheel to better control the 10-mph test speed.

Figure 7. Two-shot marking device mounted on test vehicle.

should not exceed 8 ft. In this regard, the following equation was used to calculate the maximum allowable stopping distance from a vehicle velocity of 10 mph:

$$f = \frac{V^2}{30S} \tag{1}$$

where

V = miles per hour (10);
S = distance traveled before stopping, feet; and
f = coefficient of friction.

A value of 0.40 for the coefficient f was selected as being reasonably good.

Calculation using a speed of 10 mph and an f of 0.40 shows that the pavement would have a sufficiently great skid resistance if the vehicle does not skid more than about 8 ft when braking from a velocity of 10 mph.

As indicated by Table 1, the greatest influence on the skid distance on a portland cement concrete deck was whether it was wet or dry. In all cases, however, the average skid distance was less than 8 ft, and therefore the deck surface of these bridges was considered to be of adequate roughness for safe application of water or the deicing chemical used (TKPP).

When TKPP was applied with a hand sprayer on a relatively smooth asphalt-covered bridge deck, 1 skid out of 5 was greater than 8 ft. A series of 4 tests where the bridge deck surface was wet (from high humidity) resulted in 1 skid out of 4 being over 8 ft. In this case the very old irregular surface of the bridge combined with the hand application of the chemical produced puddles of chemical and water on the surface and resulted in some of the tests exceeding a distance of 8 ft. In some cases where skid resistance of the deck surface is already borderline, the application of the deicing solution (or water) can lower skid resistance below the desired level.

If the skid test shows that a wet or dry deck can result in a skid distance exceeding 8 ft, then the application of any liquid, including plain water, can create a hazard. For example, on the Bear Creek Bridge in District 10, the average skid distance on the dry deck was 11 ft, and when wet with a TKPP solution, the average distance was 22 ft.

The skidding-car test can be used in other ways. For example, in 1 isolated test, the effectiveness of multiple applications of sand on skid resistance on compacted snow was investigated. It was found that there was no significant improvement on skid distance when sanding was done 3 times instead of once.

It is probable that the skidding-car test may be useful in determining when to request the skid trailer to determine the skid number of a pavement or to set up a priority for the chip sealing of a pavement to improve the skid number.

DISCUSSION OF RESULTS

Based on this study, it appears that in some cases salting and sanding of bridge decks may be done as a matter of "insurance" rather than as a result of actual need. For example, in one maintenance area it was found that the actual application rate of salt was an average of 0.001 lb/ft^2 of deck area. This amount of salt is ineffective for the prevention of hazardous frost conditions. However, the multiple application of the salt is the cause of much bridge deck deterioration.

Based on a preliminary study, TKPP appeared to be an effective frost-preventing chemical for temperatures greater than about 25 F on bridge decks. In addition, if there was no rainfall, it was found to be effective for periods of up to 2 weeks without reapplication.

In this second study, it was difficult to evaluate the relative effectiveness of the TKPP on California state highway bridges. This is because, for safety reasons, the chemical had to be applied to the whole surface of the bridge deck. Therefore, even though conditions were such that frost would form on the rails but not on the deck, testing of frost prevention was inconclusive. No "control" area could be provided wherein part of the deck would not receive application of the chemical. However, testing on half of a county bridge deck confirmed that TKPP was effective in preventing frost.

These results do not negate the fact that in previous work an application of the liquid TKPP to a dry pavement would, by itself, melt about 1 in. of ensuing snowfall. However, because of the high cost of TKPP, it is only considered for use on bridge decks to inhibit formation of frost where temperatures rarely go below 25 F. Chloride-type salt still remains the most economically feasible method for controlling ice on the many miles of highway pavement in snow areas.

The tests show that a 30 percent solution of TKPP applied at a rate of 0.01 lb/ft^2 of bridge deck surface is an effective frost preventative in mild climates. However, whether or not the chemical affects the slipperiness of the pavement more than water does depends on the smoothness of the pavement and perhaps the thickness and hardness of the frost layer if it is present.

At present it is not appropriate to make a cost comparison between the use of salt and TKPP to control frosting of decks. In one maintenance area it is estimated that, because of the lasting effect of TKPP, a maintenance crew could reduce the number of salting patrols by more than 50 percent by using the TKPP solution. Also, the patrols could be made during normal working hours instead of beginning them at 4:00 a.m.

It should be emphasized that TKPP is only being considered for those locations that are free of ice and snow. Such areas are normally the valley locations in California, where only the bridge deck frosts over and requires the use of a chemical to control frosting.

In the previous work it was observed that the most effective use of any tested deicing chemical was to apply it in liquid form before the conditions of frost and snow. Once the snow was packed, however, crystals of a deicer were needed to penetrate and break up the physical structure of the ice or snow.

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NEW ENGINEERING CRITERIA FOR SNOW FENCE SYSTEMS

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New engineering criteria for snow fences have been used to design a snow control system that is unusually effective in preventing drifts, improving visibility, and reducing the formation of road ice. This paper describes these criteria and the research results on which they are based. The amount of blowing snow arriving at each site was estimated from an equation relating the snow transfer coefficient, the transport distance, and the precipitation received over the contributing distance. Measurements in southeast Wyoming show the "equivalent transport distance" to range from about 500 to 1200 m. The height and number of rows of fencing at each site were selected to provide the required capacity. An equation for computing the cross-sectional area of the saturated lee drift behind the new Wyoming Highway Department standard-plan fence is given. Tall (3.8-m) fences have been used in preference to shorter ones because experience has shown taller structures to be more efficient in trapping snow and to have a much lower construction cost per unit of storage. Because studies have shown the average trapping efficiency of a fence from onset of accumulation to time of saturation to be about 85 percent, storage capacity is made about 20 percent greater than the estimated amount of blowing snow. Terrain can be used to greatly increase the capacity of snow fences; for example, capacity is increased 15-20 percent for each 0.017 rad of downslope behind a fence and about 15 percent for each 0.017 rad of upslope in the approach zone. Because wind sweeping around fence ends reduces storage capacity significantly over a distance from the ends of 12 times the height, length of fences should be at least 30 times their height and staggered barriers should be overlapped at least 8 times their height.

•AS a result of 14 years of testing snow fences to increase usable water yields from the windswept plains, we have developed several techniques that promise to improve the economy and performance of snow fence systems in other applications as well. In 1971, the Wyoming Highway Department offered a unique opportunity to test our ideas on a large scale when they asked us to engineer a snow control system for a newly constructed 70-mile section of Interstate-80 in southeastern Wyoming. At present, about $1,000,000 worth of snow fencing has been built using the innovations described in this paper. Two years' experience has demonstrated the new fence systems to be unusually effective in preventing drifts as well as for improving visibility and reducing road ice (8).

This paper summarizes the following factors that have contributed to the success of the I-80 snow fences: (a) a method of estimating snow storage capacity required at fence sites, (b) a new design for the fence itself, (c) the preferred use of tall (3.8-m) fences, (d) allowance for trapping efficiency, (e) the use of terrain to increase the capacity of fences, and (f) criteria for overlap and minimum length of fences.

ESTIMATING REQUIRED CAPACITY

Basic to our method for estimating the amount of blowing snow arriving at a fence site is the concept of "transport distance", R_a, defined as the average distance a snow particle must travel before completely sublimating (Figure 1). The "contributing dis-

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Figure 1. Diagram of the transport distance concept used to estimate sublimation loss from wind-transported snow. The transport distance, R_m, is defined as the average distance over which a snow particle (shown between the convergent dotted lines) must travel before it completely sublimates. The contributing distance, R_c, is defined as the distance upwind that contributes blowing snow to a site and may be equal to or less than R_m.

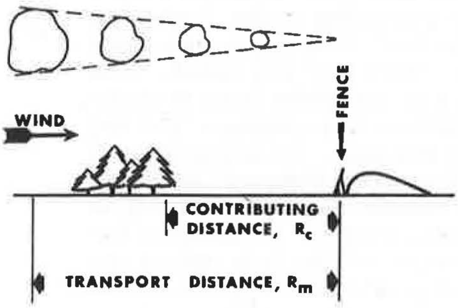


Table 1. Values for "equivalent transport distance" (θR_m) from 4 sites in Wyoming.

Site	Location	Elevation (m)	Vegetation	Year	Water-Equiv. Storage (m^3/m)	Precip. (mm)	θR_m (m)
I-80, system 1	S17, T18N, R77W	2370	Shortgrass	1971-72	85	184	925
				1972-73	116	236	979
I-80, system 12	S14, T19N, R79W	2380	Low-growing sagebrush	1971-72	138	249	1107
				1972-73	223	376	1185
Pole Mountain	S22, T15N, R71W	2440	Shortgrass	1969-70	44	171	481
				1970-71	56	195	574
				1971-72	22	81	538
				1972-73	68	239	570
Stratton Study Area (South Draw)	S25, T17N, R87W	2360	Sagebrush 0.2-0.6 m tall	1972-73	117	267	876

tance" (or fetch), R_c, upwind of a snow fence or natural barrier may be much less than R_m, depending on terrain and vegetation, but by definition cannot exceed R_m. If we assume steady, uniform flow across a smooth, horizontal surface of infinite extent (implying the absence of spatial and temporal gradients for factors affecting sublimation), then the rate of sublimation should be constant with respect to time and travel distance. Thus the amount of sublimation would be directly proportional to travel distance (R_c) so that, for a single event, as shown in an earlier paper (6),

$$Q_\ell = \frac{\theta P R_c^2}{2R_m}, \qquad R_c \le R_m \tag{1}$$

where Q_ℓ is sublimation loss over the distance R_c and θ is the ratio of the amount of snow that is relocated by the wind to the amount that falls as precipitation, P. For P, R_c, and R_m in metres, Q_ℓ is in units of cubic metres of water-equivalent per metre of width perpendicular to the wind. Average annual storage capacity, Q_c, required at a snow fence site can then be determined by subtracting sublimation loss (Eq. 1) from the total amount of relocating snow ($\theta P R_c$) at each site, using mean annual values for the variables:

$$Q_c = \theta P R_c \left(\frac{1 - R_c}{2R_m} \right), \qquad R_c \le R_m \tag{2}$$

Equation 2 was used to estimate the amount of snow storage required at each of the proposed fence sites on I-80. For this application, R_m was assumed to be 1 km (3,300 ft), based on previous studies at another location in southeastern Wyoming (6, 7). The snow transfer coefficient, θ, for each site was estimated from preliminary measurements of snow remaining on the contributing areas after drifting events. R_c was measured from aerial photographs, but for most sites was found equal to R_m. Mean winter precipitation was estimated at 244 mm (9.6 in.) from data published by the National Weather Service for nearby stations. Thus, for the extreme case where θ = 1.0 and R_c = R_m, Eq. 2 predicts an average capacity requirement of about 120 m^3 water-equivalent per lineal metre of fence (about 1,300 ft^3/ft).

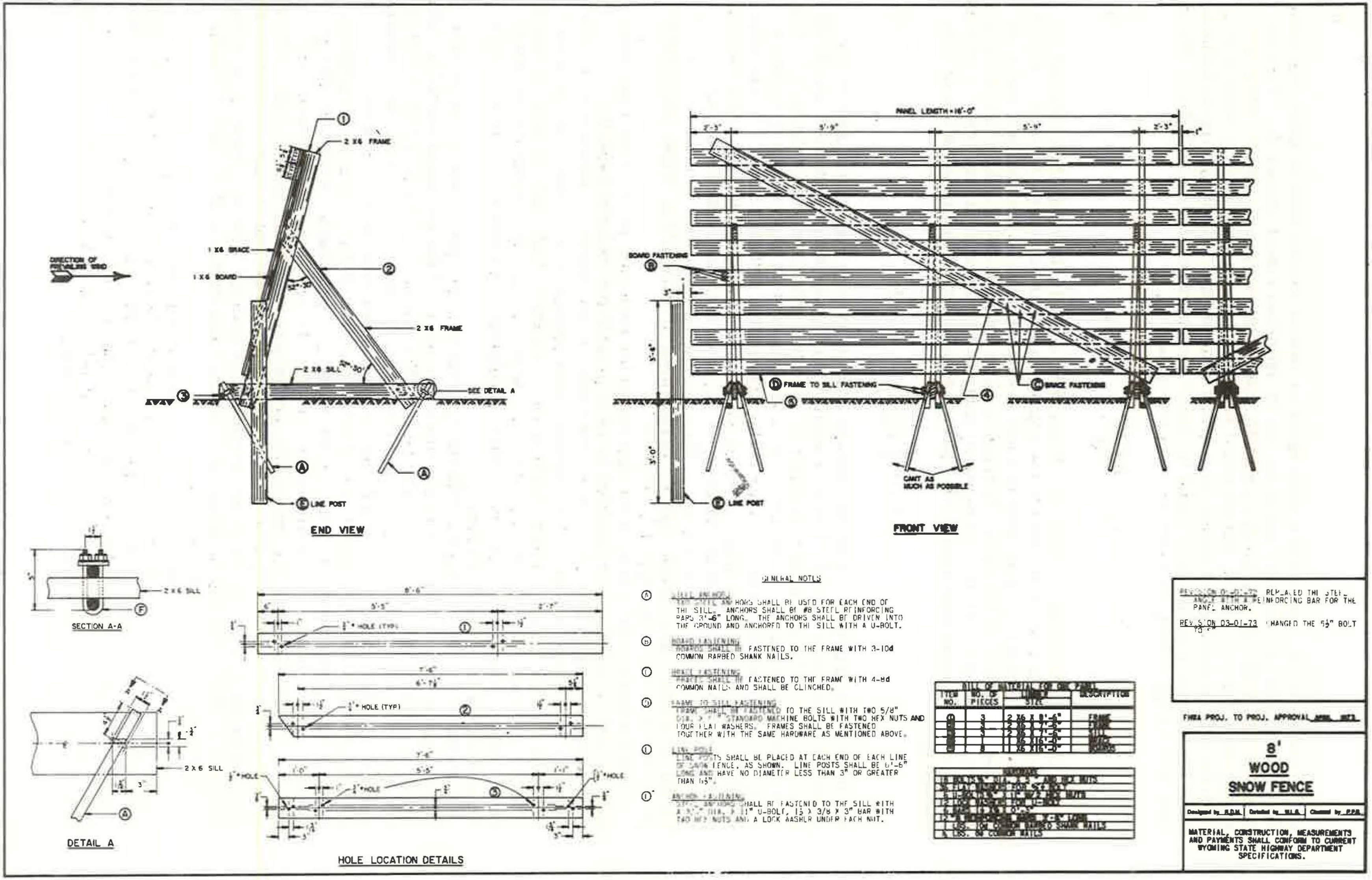
Once the quantity of blowing snow was known for each site, fence heights and numbers of rows of fencing were selected so as to provide the required capacity.

Because the initial estimates for R_m and θ were to be revised, if necessary, for the design of subsequent systems, these factors were measured at 2 sites over the winter following the first phase of fence construction. Results of that study verified the utility of Eq. 2; although the original estimates for θ were too high, they about compensated for an underestimate in R_m, and the original prediction of the amount of snow storage requirement was within 10 percent (9).

A recent model describing the sublimation rate of wind-blown snow (3) shows that R_m will depend on the relative humidity and temperature of the air, solar radiation, wind speed, and diameter of the snow particles (7). The transport distance would therefore be expected to vary from site to site and from year to year in response to these weather conditions. This variability is confirmed by our measurements of snow water-equivalent storage behind natural and artificial barriers of large capacity at different sites. Knowing the snow water-equivalent storage, in combination with precipitation measurements, permits calculation of the product θR_m (the "equivalent transport distance"). In effect, this factor represents the distance over which all the winter precipitation would have to be relocated in order to provide the amount of snow observed behind an efficient barrier by the end of the accumulation season. This combined term is introduced to allow comparison among sites where measurements of the snow transfer coefficient (and R_m) are not available.

From Table 1, which summarizes all of our available data, average values for θR_m range from about 1100 m (3,600 ft) on I-80 to about 550 m (1,800 ft) at the Pole Mountain study site. Unfortunately, the effect of elevation cannot be determined from these data because all study sites in Table 1 are at about 2400 m (7,800 ft) elevation. However, data from Straight Creek Pass (elevation 3800 m) in Colorado give a θR_m value of about 800 m (2,600 ft) averaged over 3 years of observations.

Figure 2. Wyoming Highway Department standard-plan fence, 2.4-m height.



FENCE DESIGN

The Wyoming Highway Department developed a new snow fence design in response to the need for tall fences on the I-80 project. Design features for the 2.4-m (8-ft) and 3.8-m (12.5-ft) fences are detailed in Figures 2 and 3. The basic features of this design include (a) use of horizontal slats 15 cm (6 in.) wide, spaced at 15 cm; (b) a leeward inclination of 0.26 rad (15 degrees); and (c) a bottom gap of 0.3 to 0.4 m (10 to 14 in.). The 1.8-m (6-ft) and 2.4-m (8-ft) fences are secured to the ground by metal stakes, while the 3.3-m (10.5-ft) and 3.8-m (12.5-ft) heights are guyed to anchors buried 1 m (3 ft) in the ground. A 45 m/s (100 mph) wind loading with an additional 30 percent gust factor was used in the design, and the completed structures have successfully withstood measured wind gusts up to 50 m/s (110 mph).

Our studies of this new fence show cross-sectional area A (m^2) of the lee drifts on level terrain to be proportional to fence height H (m) according to

$$A = 18 H^2 \tag{3}$$

Using a typical snow density (at peak accumulation) of 500 kg/m^3, water-equivalent capacities of fences 1.8 m, 2.4 m, 3.2 m, and 3.8 m tall are 30, 54, 90, and 129 m^3 per lineal metre of fence (325, 575, 975, and 1,385 ft^3/ft).

Other characteristics of the lee drifts at saturation (when the fence is filled) include a length of about 24H, a maximum depth of about 1.2H located 5H to 6H downwind of the fence, and a uniform tail slope of about 8.3 percent. There is reason to believe that the exceptional snow depths (and thus capacity) behind the new fences are due to the 0.26-rad inclination to leeward.

A mathematical description of the drift profile allows us to predict the capacity of these fences in irregular terrain. For this application we have found the lemniscate equation (in polar coordinates)

$$r^2 = L^2 \cos n\phi, \qquad (0 < n\phi < 90 \text{ degrees}) \tag{4}$$

to give a reasonable approximation of drift shape, where L is drift length, r is vector distance from the tail end of the drift, and the coefficient n for the vector angle ϕ is 16. The value for n is obtained by integrating for an element of area under Eq. 4 (which gives $A = L^2/2n$) and substituting Eq. 3 for A and 24H for L.

In rectangular coordinates, snow depth y at distance x from the fence is given by

$$y = L (\sin \phi) (\cos n\phi)^{1/2} \tag{5}$$

and

$$x = L \left[1 - \cos \phi \, (\cos n\phi)^{1/2} \right] \tag{6}$$

Equations 5 and 6 tend to underestimate depths in the drift nose and slightly exaggerate depths in the tail (Figure 4). This tendency is less pronounced, however, than with the rose equation ($r = L \cos n\phi$) proposed by Price (2).

FENCE HEIGHT

Data from one of our earlier experiments showed tall fences to be more efficient than shorter ones in trapping snow (Figure 5). Water-equivalent storage behind fences of different heights at various stages of snow storage prior to saturation suggests that trapping efficiency increases with increasing fence height, even at the earliest stages of accumulation. A similar conclusion was reached by Schneider (4), citing Croce's data. Since more than 95 percent of the wind-blown snow in the lowest 4 or 5 m is transported in the first metre above the ground (1), the difference in catch between fence heights of H and ($H + \Delta H$) seems to result from more than just the capture of the additional snow transported in the ΔH layer. Mean wind speed reduction behind fences has also been found to increase with increasing fence height (5), which supports the theory that collection efficiency increases with fence height.

Figure 3. Wyoming Highway Department standard-plan fence, 3.8-m height.

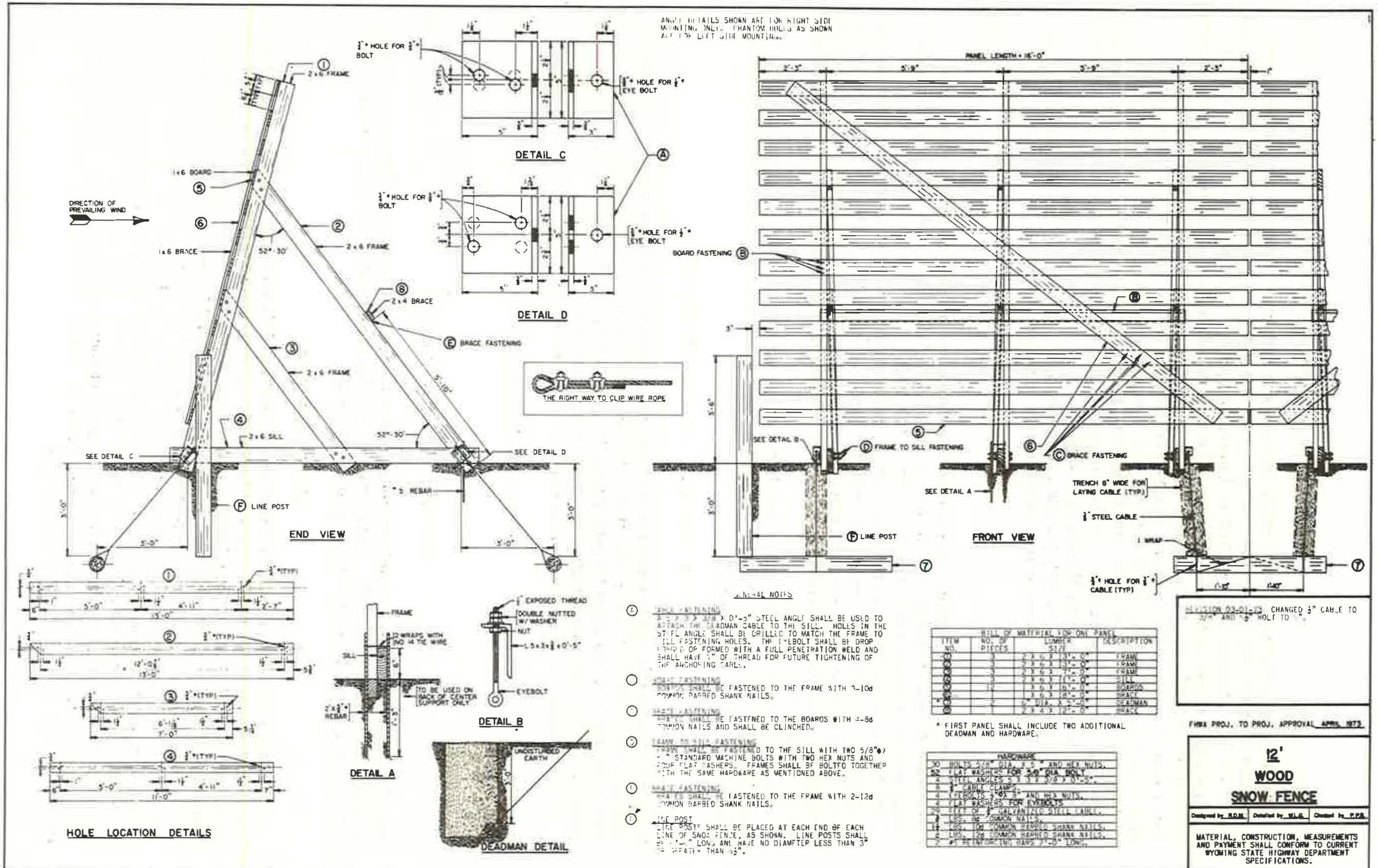


Figure 4. Average drift profile measured behind the 3.8-m fence at saturation compared with the lemniscate equation r = L cos½ (16 ϕ).

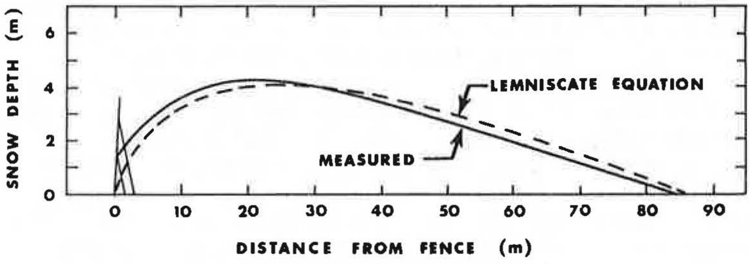


Figure 5. Lee drift water-equivalent per metre of fence (Q) as a function of fence height (H), from an earlier study in southeast Wyoming. The saturation values shown for the vertical-slat fences used in this study are considerably less than for the Wyoming Highway Department fences described in this report. Each point is the average of 4 fences.

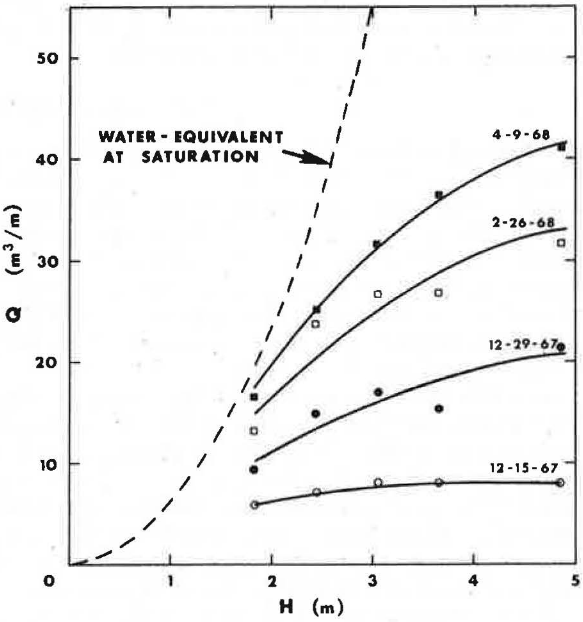
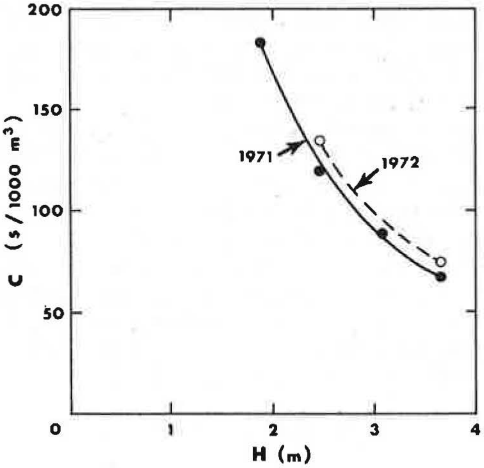


Figure 6. Construction costs (C) per 1000 m³ of water-equivalent storage as a function of fence height (H) for the two I-80 contracts.



We believe the greater trapping efficiency of the 3.8-m fences on I-80 is an important factor in the dramatic improvement in visibility (8). However, perhaps the most important reason for using tall fences is the economy of construction. Construction costs per 1000 m^3 of water-equivalent storage using a 3.8-m fence are about one-third those for a system of four 1.8-m fences of equal storage capacity (Figure 6). Costs used for this analysis are from the two I-80 snow fence contracts over the last 2 years, each totaling about $500,000. Figure 6 also suggests that the 3.8-m fence may be near the maximum height with respect to minimum costs per unit of storage.

For the extreme case on I-80 where the snow storage requirement is about 120 m^3 per lineal metre, a single row of 3.8-m fencing would provide the desired capacity (using the average year as the design criterion). However, because the efficiency of a snow fence declines as the fence fills (as will be shown in the next section), an additional row of 2.4-m fence would be prescribed, particularly in critical locations where roadway cuts have a small storage capacity or in situations where visibility improvement is the primary objective. Although there is good reason to question the practice of engineering snow control systems for the average year, an economic assessment of the problem must await more experience.

FENCE EFFICIENCY

Trapping efficiency is here defined as the percent of incoming snow that is trapped behind a barrier. When a fence is empty (at the beginning of winter), efficiency will be relatively high; once the fence is filled to capacity (or "saturated"), the efficiency must be zero. Absolute efficiency over a given interval is difficult to determine because it requires that total snow transport be known. Relative efficiency, however, may be determined by comparing performances among fences with different degrees of saturation. This comparison provides at least a preliminary idea of how much snow escapes a single fence over the course of a season and the additional fencing necessary to compensate for this escape.

For this study we compared the capture of snow among 3 tandem fences with a very large combined capacity relative to the average annual snow transport. This system is about 490 m (1,600 ft) long and consists of a 2.4-m lead fence followed by two 3.8-m fences spaced 61 m (200 ft) and 152 m (500 ft) behind the lead fence. Snow depth and water-equivalent were sampled behind the fences after each major drifting event over 2 winters. Snow depths were probed at 3-m (10-ft) intervals along 4 permanent transects, and water-equivalent was sampled with a Mount Rose sampler at 3-m intervals along 1 randomly selected transect at each fence.

A double-mass plot (Figure 7) of the change in water-equivalent storage behind the 3 fences provides some insight into how efficiency changes as a fence fills. In 1972-73, for example, the relationship between the lead 2.4-m fence and the 3.8-m fence immediately downwind was relatively constant up to the time the lead fence was about 80 percent filled. The preceding winter, this relationship showed noticeable curvature somewhat earlier (when the lead fence was about 50 to 60 percent full), probably reflecting the effect of stronger winds.

To derive a curve for this relationship, let us assume the second and third fences to be 100 percent efficient over the period of study. Of course, this assumption is not strictly true, but it is consistent with the objective of expressing efficiency of the lead fence relative to that of the second. The assumption is not too unreasonable since the second fence was only about 20 percent full by the end of the first season and only 30 percent filled by the end of the second; the third fence contained only about 10 percent of its capacity during both years, and the catch was about what would be expected from the relocation of precipitation between the last 2 fences. Using the third fence catch to estimate that portion of the second fence catch contributed by precipitation relocated between the first 2 fences, we obtain

$$\text{Efficiency of lead fence} = \frac{\Delta Q_1}{\Delta Q_1 + \Delta Q_2 - (2/3)\Delta Q_3} \qquad (7)$$

where ΔQ_1, ΔQ_2, and ΔQ_3 are the changes in water-equivalent storage over a measure-

Figure 7. Double-mass plot of the change in water-equivalent storage (ΔQ) behind 3 tandem fences at system 1, I-80.

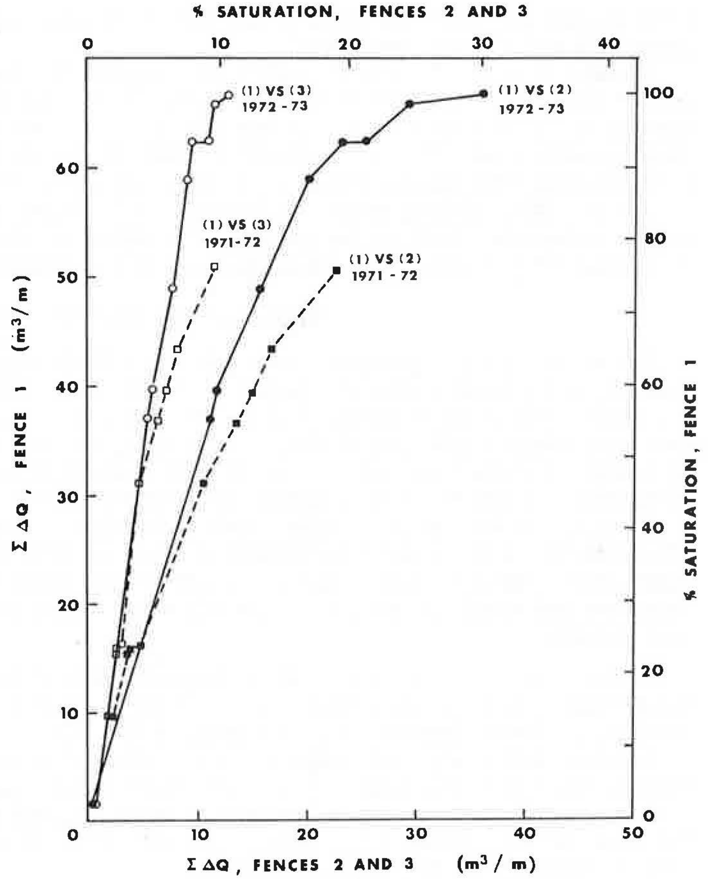
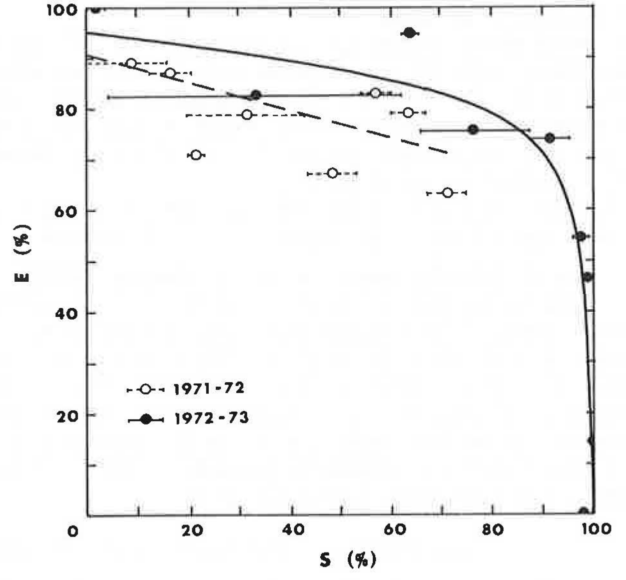


Figure 8. Efficiency (E) of a 2.4-m lead fence relative to a 3.8-m fence downwind as a function of degree of saturation (S) of the lead fence. Bars denote range of saturation over each measurement interval.



ment period, and the $2/3$ factor accounts for the relative spacing between the 2 pairs of fences (61 and 91 m respectively).

Results from Eq. 7 were plotted against degree of saturation (Figure 8); average curves show that efficiency decreases slowly as a fence fills, with between 70 and 80 percent of the incoming snow still being trapped by the time the fence is 75 percent full. This result agrees with our observations that fences markedly improve visibility on the roadway even when fences are filled to 60 percent or more of capacity (8).

For the 1972-73 data, average efficiency of the fence, from onset of accumulation to time of saturation, is about 85 percent. We therefore recommend that storage capacity be at least 20 percent greater than the amount of blowing snow estimated from Eq. 2.

TERRAIN INTERACTIONS

The scope of this paper precludes a detailed discussion of the complex relationships between terrain and fence performance. A few general rules have contributed substantially to the success of the I-80 system, however, and so are briefly outlined here. Our applications have been limited to rolling topography with slopes of 20 percent or less, and our guidelines are not necessarily applicable for steeper terrain or for fences other than the new Wyoming Highway Department design (Figures 2 and 3).

Terrain can be used to greatly increase the storage capacity of a snow fence, making it possible for a short fence to contain as much snow as a much taller (and thus more expensive) structure. Conversely, certain terrain situations detract from fence performance and should be avoided. The following rules condense some of the more common situations:

1. For gently rolling topography with gentle to moderate slopes, fence performance is affected by the terrain extending from about 45 m (150 ft) upwind (approach zone) to about 90 m (300 ft) leeward (exhaust zone) of the snow fence.
2. On uniform slopes of less than 10 percent, either upward or downward with respect to the prevailing wind, a fence will store as much snow as on level terrain.
3. Depressions in the lee drift zone serve to augment snow storage capacity. The increase can be estimated by plotting Eqs. 5 and 6 relative to a horizontal surface extended leeward from the fence.
4. Downward slopes in the exhaust zone increase storage capacity; as a preliminary guide, capacity is increased by 15 to 20 percent for each 0.017 rad (1 degree) of slope up to 0.17 rad (10 degrees).
5. Upward slopes in the approach zone (up to 0.17 rad) have also been observed to increase fence capacity. As a preliminary guide, effective fence height increases about 0.15 m (0.5 ft), with a resulting capacity increase of about 15 percent, for each 0.017-rad increase in slope. Drift length is also increased according to this rule. This effect has been confirmed only for the new Wyoming Highway Department fence design described earlier in this report.
6. Upslopes and hills in the exhaust zone generally decrease fence capacity, except as noted in rules 2 and 5 above, and should be avoided.

The largest drift we have observed behind any of the I-80 fences (Figure 9) demonstrates some of the guidelines given above. In this example, a 3.8-m fence is located on a ridge crest. The upslope approach, approximately 0.061 rad ($3\frac{1}{2}$ degrees), has resulted in a drift about 0.6 m (2 ft) deeper than would be expected with a level approach (rule 5). Storage capacity is further enhanced by the 0.15-rad (6-degree) downslope in the exhaust zone (rule 4). The cross section of this drift was 445 m^2 (4,800 ft^2), or about twice that expected behind a 3.8-m fence on level terrain. The capacity of the fence at this location is estimated to be about 320 m^3/m water-equivalent and would be expected to fill only about 1 year out of 100.

END EFFECT, OVERLAP, AND MINIMUM LENGTH

Criteria for overlapping staggered fences, as well as for minimum length, must be developed from a knowledge of how the trapping efficiency of a snow fence varies as a function of distance from the end of the fence. For a fence oriented exactly normal to

Figure 9. Cross section of the largest drift yet measured behind the I-80 fences, showing the effects of terrain on storage capacity of a 3.8-m barrier at system 14A. A saturated drift on level terrain is shown for comparison.

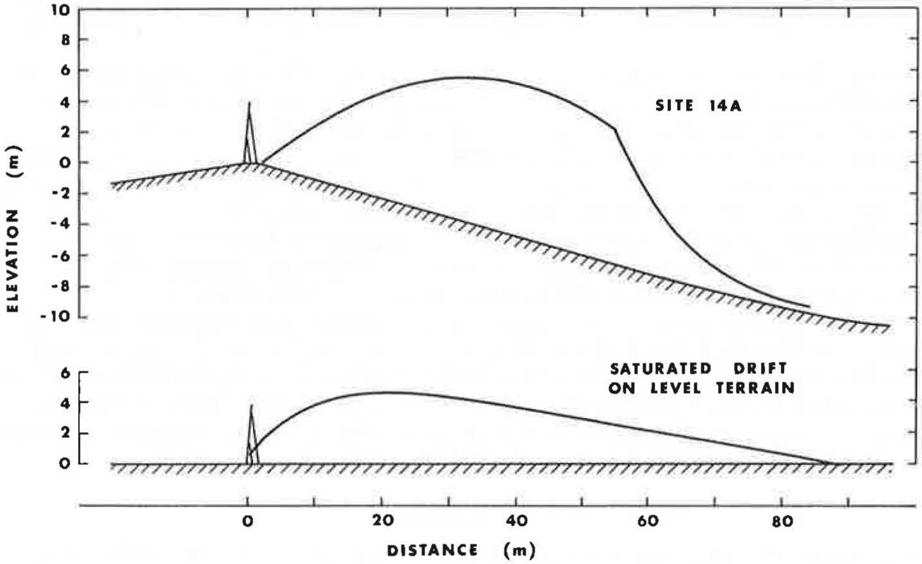
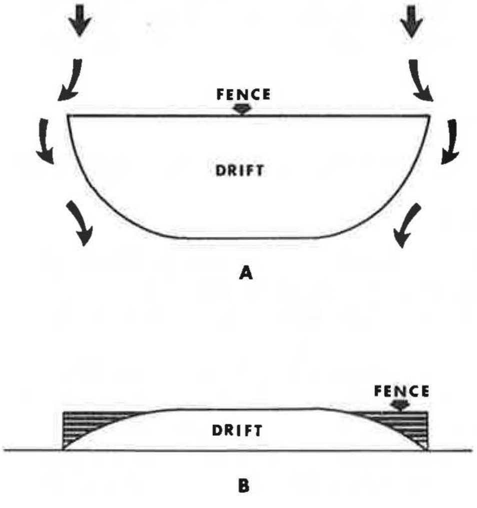


Figure 10. The ends of a drift rounded by wind sweeping around the ends of the fence: (A) plan view, (B) elevation.



the wind, the ends of the lee drift at saturation will be rounded by wind sweeping around the fence (Figure 10). This effect is due to the generation of turbulent eddies at the fence boundary, an acceleration of the converging air flow at the ends of the fence, and the response of the air flow to the lateral pressure gradients developed behind the barrier. Of course, oblique winds tend to accentuate this rounding on the end exposed to the wind.

Our data from 6 fences of different heights show this end effect to extend inward as far as 12H from the end of the fence (Figure 11); at a distance of 5H, the drift cross section is only about 80 percent of maximum. Based on this information, we recommend a minimum overlap in a series of staggered fences of about 8H, which will reduce the escape through the overlap section to less than 10 percent (Figure 12). This recommendation assumes drifting winds to be relatively constant in direction and also ignores the tendency of blowing snow to weave its way around staggered barriers. Overlap should be extended to 10H or more in cases where wind directions are variable or where terrain might tend to reinforce the snaking tendency of the wind.

By using the data from Figure 11, it is possible to compare capacities of different lengths of fences relative to a fence of infinite length. The end effect is a significant factor (Figure 13); for example, a fence 10H in length will be able to contain only about 60 percent of the snow trapped behind the center 10H of a very long fence. Based on this analysis, we recommend that all fences be at least 30H in length; shorter structures are obviously much more expensive in terms of cost per unit of storage.

CONCLUDING REMARKS

Although the length of this paper does not permit a discussion of other guidelines, such as those for optimizing fence configurations in instances where winds are oblique to highway alignment, the reader can develop these for himself from the basic concepts outlined.

Properly engineered snow fence systems are a powerful tool for snow control, and it is unfortunate that earlier applications of improperly designed fences have made some engineers skeptical of their potential. Indeed, the benefits of improved visibility and reduced ice formation have only now come to light with the I-80 installations. The criteria proposed here should help bring snow control technology up to date with today's standards of highway engineering.

ACKNOWLEDGMENT

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Figure 11. Cross-sectional area (A) of the lee drift at saturation (expressed as percent of maximum value in center of fence) as a function of distance (D) from the end of the fence (in multiples of fence height H).

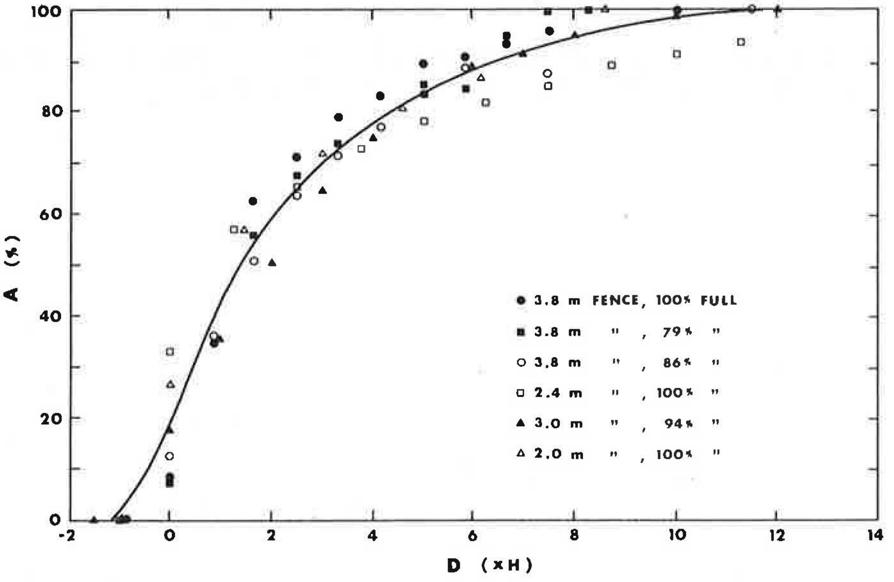


Figure 12. Escape of blowing snow through an overlap section (in percent of total ambient transport) in relation to amount of overlap and distance from center (in multiples of fence height H).

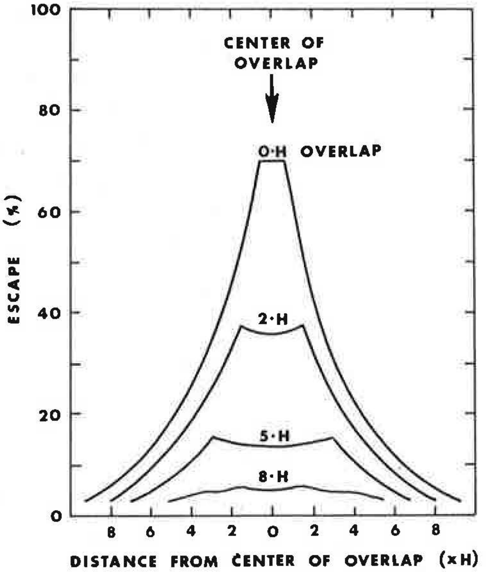
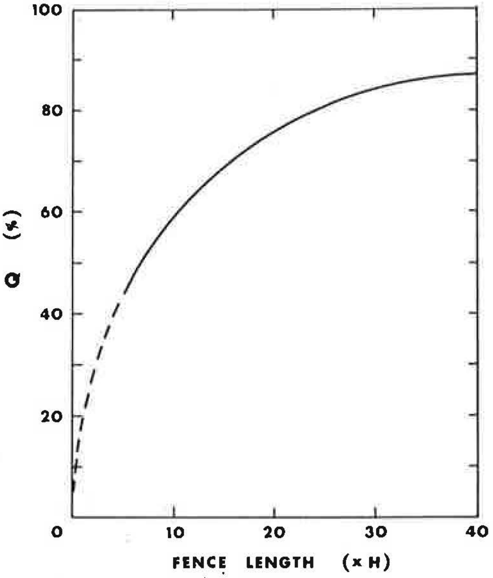


Figure 13. Total storage capacity Q (in percent of maximum possible) as a function of fence length (in multiples of fence height H).



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FLAT PEA FOR HIGHWAY SLOPES IN MASSACHUSETTS

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The tremendous cost of repairing highway slopes eroded because of poor vegetative cover is a serious problem. Flat pea (Lathyrus sylvestris L.), a perennial herbaceous legume, is an excellent plant for erosion control and a good soil stabilizer. Because it was not being used in the state, it was essential to determine its adaptability to the climate and to the acidic, infertile cut and fill slopes that lack topsoil. A greenhouse experiment was conducted using 2 soils, one very acidic and low in fertility and the other only slightly acidic and of medium fertility, to determine the plant's response to lime and fertilizer. The plants in the very acidic soil that received fertilizer and both lime and fertilizer responded well. It was found that the pH requirement of flat pea is not so critical as that of crownvetch. Based on the results obtained in the greenhouse studies, successful plot plantings and seedings were made throughout the state over a 4-year period. Seedings made in the spring or as dormant seedings in late fall before the ground freezes produce best results. Late summer and fall seedings are risky because the seedlings generally have too much competition from grasses and weeds.

•FLAT PEA (Lathyrus sylvestris L.) is a climbing herbaceous perennial legume with long, vein-type stems. The leaflets are narrow and about 5 cm (2 in.) in length. The plant is similar in appearance and growth habits to the ornamental or everlasting pea (Lathyrus latifolius L.) (2). When in blossom in June and July, the flowers are an attractive rose color but are less conspicuous than those of the garden variety. The plant has a procumbent growth habit, producing a dense mat of leaves and stems from 61 to 95 cm (2 to 3 ft) high (5, 8). Once established in an area, it is permanent and resists invasion from other species. Flat pea is deep-rooted and spreads by underground root stocks. An excellent plant for erosion control, it is hardy, drought-tolerant, and adapted to a wide variety of soil conditions (3, 6, 7). It is best suited to well-drained soils and does well on low-fertility sites such as sands and gravels (5).

There is increased interest in the replacement of grass by crownvetch and other legumes for erosion control and full cover on critical highway sites in Massachusetts. Grass is seeded on all disturbed areas along highways for fast cover and for control of erosion. However, establishing good grass cover is sometimes a problem, especially on fill and cut slopes where soil materials are acidic, infertile, devoid of organic matter, and poor in physical condition. Many areas seeded to grass soon deteriorate, and erosion occurs. Reseeding is very expensive and may not be a permanent solution to the problem. The use of other adaptable herbaceous plants is necessary in critical areas where grass will not solve the problem.

At this time, crownvetch is being used throughout Massachusetts as a supplement to grass seedings. Flat pea also seems promising and should be considered for slope seedings because it is an excellent conservation cover plant. Because erosion damage calls for additional expenditures of time and money, economics becomes a primary motivation for developing methods and techniques of establishing vegetation on newly

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graded areas and slopes (1). This is also true for established slopes that are eroding and whose cover is deteriorating.

A review of literature shows that very little has been done with flat pea in the United States. The Soil Conservation Service has done more testing than any other agency of various strains of flat pea for erosion control, soil stabilization, and establishment on logging roads, dam sites, gravel pits, and mine spoils (4). It was found that flat pea has excellent stabilization qualities, is drought resistant, and thrives in moderately acidic soils or in those soils that may be slightly more acidic than crownvetch will tolerate (4, 6, 8). After years of selection, the SCS Plant Materials Center in Big Flats, New York, released under the name of "Lathco" a fast-spreading flat pea with seedling vigor and the quality of producing dense vegetative cover (5).

Lathco flat pea has been tested and has proved to be an excellent conservation plant for the Northeast. It has been successfully established on logging roads, utility rights-of-way, and openings created by construction in wooded areas (4, 5). It was found that a solid stand of flat pea inhibits the reinvasion of forest species (4). A seeding of various grasses and legumes on a dam site in Berkshire County, Massachusetts, resulted in flat pea's having provided the thickest cover of many species tested by the end of the second summer (9).

Flat pea had not been used on roadsides in Massachusetts, but because it appeared to have good possibilities, a greenhouse experiment was conducted from December 1969 to April 1970 to study its response to lime and soil fertility. Also, late in 1970 and in 1971, a series of plots was set up along a roadside to determine the best seeding time for successful establishment of this legume under Massachusetts climatic conditions.

GREENHOUSE EXPERIMENT

Materials and Methods

Two soil types, a Hinckley sandy loam with a pH of 4.2 and a Scarboro sandy loam with a pH of 6.3, were used. The soil analysis data are given in Table 1. Commercial fertilizer, 28-97.8-186.6 kg of N, P, K per hectare (25-87.4-166.6 lb of N, P, K per acre), was used. The lime treatments for the Hinckley soil (4.2 pH) and Scarboro soil (6.3 pH) were at the rates of 5600 kg per hectare (5,000 lb per acre) and 1120 kg per hectare (1,000 lb per acre) respectively.

Various soil treatments were used and are given in Table 2. The experimental design was a random block arrangement with 3 replicates. Prior to seeding, the seeds were inoculated. Twelve seeds were then planted per plastic pot, which measured 15 cm (6 in.) deep and 13 cm (5 in.) wide. After the seeds had germinated, excess seedlings were removed to leave 6 plants per pot. The soil in the pots was watered to field capacity and subsequently watered when the moisture content in the pots reached approximately one-half field capacity. Seed germination and emergence were slow but good in both soils. The plants were harvested 14 weeks after seeding.

Results

By using height and dry weight of plants to show their response to lime and fertilizer it was found that, in regard to the very acidic Hinckley soil, there were no significant differences between the control plants and those in the lime-surface and lime-mixed treatments (Tables 2 and 3). It is possible that flat pea will tolerate acidic soil conditions. There were no significant differences among the plants in treatments 4 through 7. Treatments of fertilizer alone or fertilizer and lime combined, either applied on the surface or mixed in, produced similar results (Figure 1).

Among the plants grown in the slightly acidic Scarboro soil, there were no significant differences in response, even in the control plants (Tables 2 and 3). It appeared that the soil pH and fertility levels were adequate for the establishment of flat pea. There was a large difference in height and dry weight response in the control plants of the two soils because of differences in fertility levels and pH. The low fertility levels under the acidic soil conditions of the Hinckley soil were overcome, it seems, by applied fertilizer. Lime alone did not significantly increase plant growth.

Table 1. Soil analysis data.

Soil	pH	Lime Requirement (kg/ha)	Element Content (kg/ha) Ca	K	P	Mg
Hinckley sandy loam	4.2	6720	1120	268	27	27
Scarboro sandy loam	6.3	0	3584	560	224	112

Table 2. Comparative response of top growth of flat pea to various lime and fertilizer treatments in centimeters (average of 3 replicates).

Treatment	Hinckley Soil, Very Acidic	Scarboro Soil, Slightly Acidic
1. Control, no treatment	7.3 a	16.0 a
2. Lime, surface	8.1 a	15.6 a
3. Lime, mixed	8.3 a	13.7 a
4. Fertilizer, surface	14.7 b	16.8 a
5. Fertilizer, mixed	12.7 b	14.1 a
6. Lime and fertilizer, surface	14.4 b	15.5 a
7. Lime and fertilizer, mixed	11.6 b	15.0 a

Note: Treatment means in the same column having no letters in common are significantly different at the 5 percent level, using Duncan's New Multiple Range Test.

Table 3. Comparative growth response of flat pea to lime and fertilizer treatments using the average dry weight in grams of 6 plants (average of 3 replicates).

Treatment	Hinckley Soil, Very Acidic	Scarboro Soil, Slightly Acidic
1. Control, no treatment	0.49 a	2.68 a
2. Lime, surface	0.41 a	2.30 a
3. Lime, mixed	0.43 a	1.79 a
4. Fertilizer, surface	1.74 b	2.47 a
5. Fertilizer, mixed	1.52 b	1.97 a
6. Lime and fertilizer, surface	1.89 b	1.97 a
7. Lime and fertilizer, mixed	1.44 b	2.10 a

Note: Treatment means in the same column having no letters in common are significantly different at the 5 percent level, using Duncan's New Multiple Range Test.

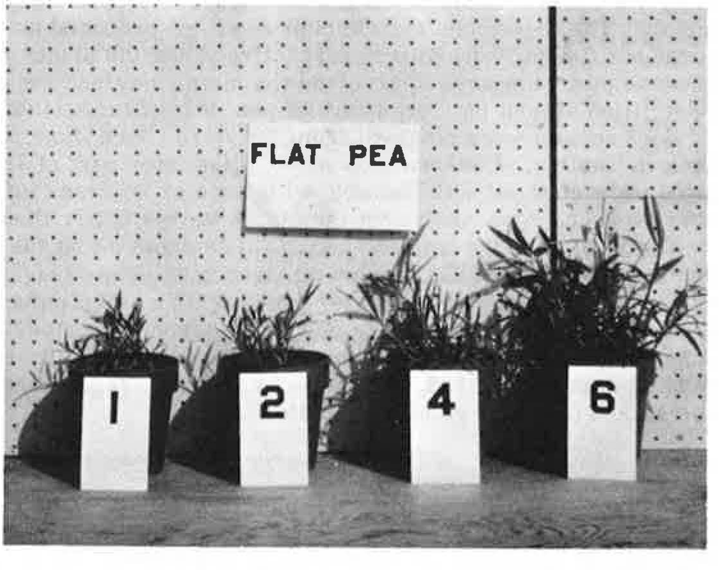

Figure 1. Growth response of flat pea grown in the very acidic Hinckley soil: 1 = control; 2 = lime, surface; 4 = fertilizer, surface; 6 = lime and fertilizer, surface.

ROADSIDE EXPERIMENT

Materials and Methods

An east-facing, 3:1 cut slope on I-86 in Sturbridge, Massachusetts, was the site of the roadside experiment. The brown-colored till was mostly parent material and very stony. A mechanical analysis of the soil showed that it consisted of 71 percent sand, 22 percent silt, and 7 percent clay. It was classified as a stony sandy loam. Because of the many stones on the site, it was almost impossible to develop a good seed bed. The mixing of the limestone and fertilizer and the incorporation of the flat pea seed were done in 3 operations by back-grading with a bulldozer blade. Limestone was applied at the rate of 3360 kg per hectare (3,000 lb per acre) and 0-8.7-16.6 (N, P, K) fertilizer at the rate of 896 kg per hectare (800 lb per acre). Inoculated Lathco flat pea seed was broadcast at the rate of 23 kg per hectare (21 lb per acre) and mulched with hay at the rate of 2240 kg per hectare (1 ton per acre). Plots 7.6 by 15.2 m (25 by 50 ft) were seeded starting December 1, 1970, a dormant seeding, and continuing each month from April through October 1971. An application of 0-8.7-16.6 (N, P, K) fertilizer at the rate of 392 kg per hectare (350 lb per acre) was given to all plots in June 1972.

Seedling or plant counts were taken every month from 4 squares, each 0.3-m (1-ft) on a side, selected at random to determine establishment and survival for the various seeding dates. Data on plant height were also taken (Figure 2).

Results

Table 4 gives the average number of seedlings and heights of plants for each monthly seeding date. On the date of each successive seeding, data were taken on the seedings made the previous months. The number of seedlings per square foot may appear low, but since there are only about 15,000 flat pea seeds per 453 g (1 lb) and the rate of seeding was 23 kg per hectare (21 lb per acre), one could expect only about 7.5 seeds per 0.3-m (1-ft) square.

The dormant seeding produced the least seedlings per 0.3-m square. However, at the end of the second growing season, this plot had produced a good stand of flat pea. In it, also, was a dense stand of grass and clover that had been introduced with the grass mulch. The September and October seedings produced an excellent and a fair seedling count per 0.3-m (1-ft) square respectively, but the plants were small. In 1972, cover in these plots appeared sparse and the plots contained weeds and grass; in 1973, they were filled almost entirely with flat pea, but still contained weeds.

Best results were obtained from the April, May, June, and July seedings, as can be seen in Table 4. Observations made in the later part of July 1972 indicated that these plots were covered with flat pea, with little or no grass or weeds. The August seeding also produced good cover, but the plants were smaller than those in plots seeded earlier.

The results of the time-of-seeding data showed that the earlier seedings of flat pea had a good chance to establish well-developed plants (Figure 3); later seedings produced smaller plants due to the shorter growing time. September and October seedings did not produce full cover even by the end of the second summer. Blossoms were observed only on plants from the December and April through July seedings during the second year of growth. In 1973, the plants in all plots, regardless of seeding date, had blossomed and produced good-to-excellent cover.

SUMMARY AND CONCLUSIONS

It appears that flat pea is somewhat tolerant of acidic soil conditions. It has been found growing on sites with a pH of 5.0 (3). However, it establishes itself more rapidly when the pH is nearer the neutral point and fertility levels are high. In order to introduce flat pea on roadside slopes in Massachusetts where the soil is mostly subsoil and parent material, it is recommended that the soil be limed according to the lime requirement test and that fertilizer be applied prior to seeding.

Seeding can be accomplished from the time one is able to work the soil in the spring until the latter part of June. July and August seedings are, naturally, dependent on the

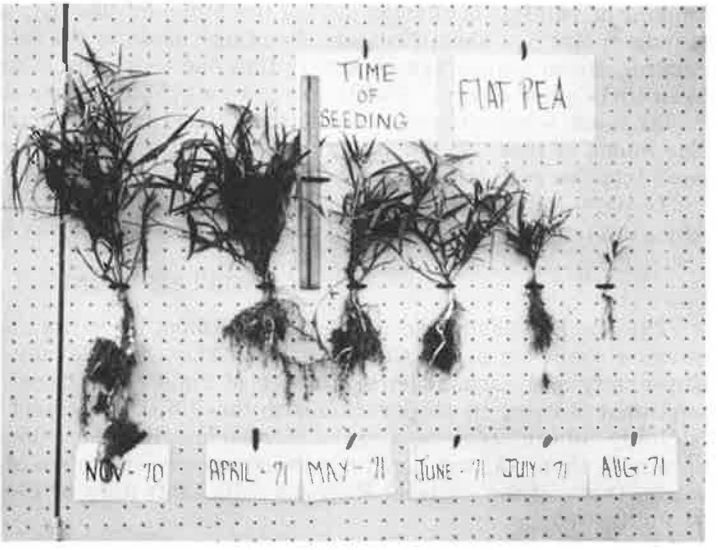

Figure 2. Size of flat pea plants seeded December 1, 1970, and in April, May, June, July, and August 1971. Picture taken in September 1971.

Table 4. Number and heights (average of 4 readings) of flat pea plants per 0.3-m (1-ft) square.

	1971										1972	
	June		July		Aug.		Sept.		Oct.		June	
Date of Seeding	No.	Height (cm)	No.	Height (cm)	No.	Height (cm)	No.	Height (cm)	No.	Height (cm)	No.	Height (cm)
Nov. 23, 1970	2	3.8	2	5.5	2	8.6	2	9.1	2	13.9	2	38.8
April 4, 1971	3	4.5	4	6.3	4	11.4	4	14.7	4	17.7	6	40.3
May 12, 1971			5	11.6	5	20.5	6	25.4	5	26.4	5	55.8
June 7, 1971			3	5.3	4	13.7	4	17.7	4	18.5	5	44.9
July 6, 1971					5	6.6	6	9.3	6	10.4	6	25.6
Aug. 6, 1971							4	6.8	6	7.1	6	18.0
Sept. 8, 1971											6	6.0
Oct. 5, 1971											3	3.5

Figure 3. June seeding of flat pea. Picture taken in June the second year shows complete cover.

amount of rainfall occurring during the summer months; if rainfall is adequate, good stands of flat pea should result. Seedings made in the fall of the year are not so successful; these stands are generally thin due to winter injury, especially when there has been little snow cover. Weeds are also a problem when the stand is sparse.

Dormant seedings made before the ground freezes produce good stands of flat pea. The seeds of this legume are large, and best results are obtained by incorporating the seed into the soil and mulching the area.

To date, successful plantings have been made on deteriorating slopes in the 8 highway districts of Massachusetts, and the cover of flat pea is excellent.

ACKNOWLEDGMENTS

The flat pea seed used in these experiments was obtained from the Soil Conservation Service Plant Materials Center at Cape May, New Jersey. This work was done at the University of Massachusetts, College of Food and Natural Resources Agricultural Experiment Station, in cooperation with the U.S. Department of Transportation, Federal Highway Administration, and the Massachusetts Department of Public Works. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Federal Highway Administration or the Massachusetts Department of Public Works.

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A MINIMUM-COST, ENVIRONMENTALLY SAFE PROGRAM OF HERBICIDE MAINTENANCE FOR INDIANA ROADSIDES

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The purpose of this study was to design a minimum-cost maintenance program for control of vegetation along Indiana roadsides. Mechanical and chemical methods were combined to maintain healthy turf at low cost. A 3-year (environmentally safe) spraying rotation in combination with mowing was recommended and implemented. It provides a maximum-benefit, low-cost maintenance program for the state with cost savings in excess of $200,000 annually.

•WITH the development of the Interstate System, the management of turfed roadsides is an increasingly important function of highway departments. Divided lanes, median strips, and broad rights-of-way are an integral part of the modern highway, and the management of turfed roadsides is no longer a minor consideration of roadside maintenance. Healthy roadside turf prevents soil erosion, protects adjacent cropland from invading weeds, and provides features of beauty, safety, and convenience.

Rights-of-way are designed for safety and convenience. They must be maintained if the safety and convenience features are to be preserved.

What happens when roadsides are not maintained in a turfed or semiturfed condition? Even with careful landscaping and restricted mowing, areas that are not maintained revert to native vegetation. Tall weeds and wild grass kill turf by shading, only to die back during the winter to leave patches of bare soil open to erosion (Figure 1). In as little as 1 year, tree seedlings and root sprouts may become established on unmaintained rights-of-way. After a number of years, these sprouts become brush and eventually trees. Brush obscures vision, adding a hazardous condition to an otherwise safe highway. If sight distances are reduced by vegetation below minimum specifications, the state is liable to litigation in the case of accidents. Trees immediately adjacent to a major highway present an obvious safety hazard. Such trees and brush must be removed at considerable expense and the turf reestablished to prevent additional erosion. The costs of tree and brush removal and reestablishment of turf exceed the costs of modest annual maintenance programs.

Turf stabilizes the soil and prevents erosion. Sediment from soil erosion is the major pollutant of Midwestern waterways; the problem would only increase in severity if roadside rights-of-way were not maintained.

Along the Interstate System and major state highways in Indiana and throughout most of the Midwest, the roadsides are already turfed, principally bluegrass, and mostly free of trees between the edge of the shoulder and the fence-line (Figure 2) except for steep banks and certain scenic areas. The soil is mostly of high fertility, and much of the roadside borders on cultivated agricultural land of high productivity. Of major concern in protecting both the established roadside turf and the adjacent cropland is the control of weeds and brush. The control methods must be effective, inexpensive, and not deleterious to either the environment or adjacent crops.

The program recommended and implemented for the State of Indiana involves combined herbicide and mowing treatments. Environmental and crop safety are ensured by use of nontoxic amine formulations of herbicides and late-fall and early-spring ap-

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Figure 1. Unsprayed section of I-69 near the Indiana-Michigan border. Tall weeds and grass have smothered out the turf leaving patches of bare soil subject to erosion. Photographed June 2, 1973.

Figure 2. Sprayed section of I-69 near the Indiana-Michigan border. This portion received the fall-spring 2,4-D application cycle in the 1972-73 season as described in Table 1. The roadside is essentially weed-free. Photographed June 2, 1973.

Figure 3. Unsprayed median of I-69 near the Indiana-Michigan border. Numerous weeds are seen in the foreground. Photographed June 2, 1973.

plications. Effectiveness and low cost are provided by a 3-year rotation in combination with reduced mowing.

EFFECT OF FALL APPLICATION

Applications of herbicides in the fall prevent growth of weeds the following spring and summer and provide maximum safety to the environment. Implementation of results obtained under the Joint Highway Research Project at Purdue University (1) established the effectiveness of fall applications of herbicides to control problem weeds along roadsides (Figures 1-4). Applications are made from September 1 until the first killing frost (Table 1).

As the first killing frost approaches, hard-to-kill perennial weeds move all available materials into the underground parts of the plants. Herbicides applied at this time reach the underground plant parts through translocation activity when these parts are most susceptible to the killing action of the herbicide (1, 2). Dandelion, plantain, buckhorn, creeping charlie, milkweeds, Canadian thistle, dock, and other problem roadside perennials are among the weeds susceptible to fall applications of herbicides.

Plants with a biennial growth habit are also controlled by fall applications of herbicides. Wild parsnip and wild carrot are examples of especially troublesome roadside weeds with biennial growth habits. Plants germinate in the spring and summer to overwinter as small plants with a whorl of leaves about grass height in mowed turf. The following spring, the plants produce a flowering stalk up to 5 ft high that is unsightly, obstructs vision, kills turf by shading, and produces abundant seed to ensure reinfestation. Herbicide applications in spring or summer are ineffective in killing the plants or even in preventing production of viable seed because the plants grow rapidly in early spring. They are frequently in full flower by May 15. Fall applications of herbicide give complete control of these weeds for up to 3 years (Figure 6), whereas spring applications of twice the amount of herbicide do not provide even single-season control.

Winter annuals are a third category of weeds controlled by fall applications of herbicides. Winter annuals germinate in the fall, enter a rosette stage in which they overwinter, and flower in early spring. Examples include henbit, shepherd's purse, yellow rocket, and most of the wild mustards. These plants are killed in the fall as they germinate through pre-emergence action of the herbicides.

The only category of plants that escapes a fall application of herbicide is the summer annuals such as pigweed, ragweed, lambsquarter, and velvet leaf. These plants are common weeds of croplands but seldom invade healthy turf. They are encountered only infrequently along Indiana's roadsides.

An important advantage of fall applications of herbicides is that of environmental safety. In the fall, desirable plants in cropland or gardens and shrubs and flowers in lawns, golf courses, or recreational areas and in roadside plantings and forests are dying, dead, or dormant. Trees and shrubs are losing their leaves and, unlike the plants to be controlled, escape the herbicide. Problems of drift onto soybean or tomato fields are eliminated because the growing season is over. By the following spring, soil residues are completely dissipated, especially with the biodegradable herbicides such as 2,4-D.

AMINE FORM RECOMMENDED

Only nontoxic 2,4-D amine formulations of herbicide are recommended. The environmental safety of various roadside herbicides was evaluated in laboratory, greenhouse, and field investigations (1, 3, 4). The potential hazard of pure 2,4-D to fish or algae from terrestrial runoff water (concentrations of 0.1 ppm or less) or direct or accidental contamination (3 lb/acre applied directly to 6 in. of water) is nil. Studies with formulated materials, however, showed that 2,4-D ester derivatives are substantially more toxic than the parent acid; fish and phytoplankton kills result at the 3 lb/acre rate applied directly to water.

In June 1971, a recommendation was made to the Indiana State Highway Commission that only nontoxic amine and salt formulations of 2,4-D be used for roadside spraying and that use of toxic ester formulations be discontinued. The recommendation was

Figure 4. Sprayed median of I-69 near the Indiana-Michigan border. This portion received the fall-spring 2,4-D application cycle in the 1972-73 season as described in Table 1. The area is essentially weed-free. Photographed June 2, 1973.

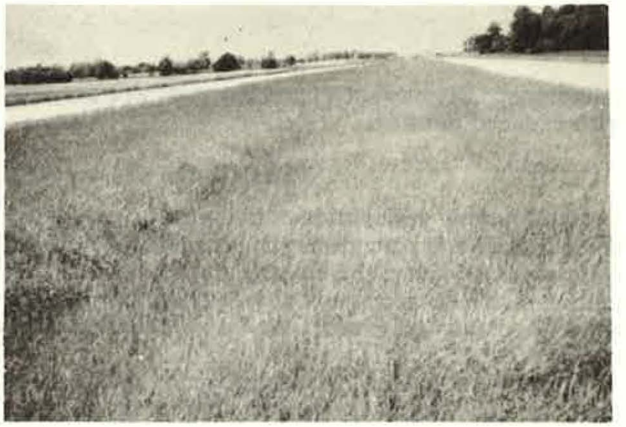


Table 1. Program of alternating fall and spring applications of herbicide implemented in the spraying-by-contract program for Indiana.

Material: 2,4-D amine form concentrate containing at least 4 pounds of acid equivalent per gallon. Ester formulations of 2,4-D are not used due to possible environmental hazards.
Rate: Material is mixed at the rate of 2 gallons of 2,4-D concentrate to 100 gallons of water. The mixture is applied at the rate of 40 gallons per acre.
Schedule of application:
Fall: September 1 to first killing frost.
Spring: March 15 to April 30.

Table 2. Control of perennial weed species by fall applications of 2,4-D.

	Plants/100 ft^2	
Weed Species	Control	2,4-D
Dandelion	588	71
Plantain	155	3
Wild parsnip	211	0
Curled dock	19	0

Note: The 2,4-D was applied (2.7 lb/acre) using conventional truck-mounted equipment by a contractual herbicide applicator on October 4, 1971; evaluations were December 4, 1971.

Figure 5. Portion of US-421 north of Lafayette, Indiana, in White County. The right side of the road received a single fall application of experimental formulation M-3766 (3 parts picloram and 1 part 2,4-D) at a rate of 2 lb active ingredient per acre. The left side of the road was unsprayed. Photographed in the spring following application.

Figure 6. Wild parsnip plots on July 25, 1972, approximately 2 years after treatment with a mixture of ¾ lb per acre of picloram plus ¼ lb per acre of 2,4-D. The unsprayed area on the left shows numerous plants of wild parsnip 4 to 5 ft high that have matured and produced seed. The treated area on the right is free of weeds.

accepted and, beginning in the fall of 1971, use of 2,4-D has been restricted to amine formulations.

3-YEAR SPRAYING PLAN

A 3-year spraying rotation minimizes costs and maximizes effectiveness. In 1971, approximately 1,500 linear miles of highway received a fall application of 2,4-D between September 15 and October 15 under the spraying program by contract. Evaluations of test plots throughout the state showed the treatment to be extremely effective, with weed control 2 months after treatment ranging from 85 percent to over 95 percent (Table 2). The fall application was followed by a second application in early spring (Table 1). The spring application was to control seedlings and new growth that escaped the fall application. It, too, was effective and environmentally safe. The spring application was scheduled early enough to avoid crops and at a time when most trees and shrubs were still in a dormant or near-dormant condition. The combined spring and fall applications were sufficiently effective to eliminate all midsummer chemical treatments (Figures 1-4). This was advantageous from an environmental standpoint because the midsummer treatments were those most likely to cause injury to nontarget vegetation. The direct cost saving to the state from the Herbicide Treatment Program by Contract alone was an estimated $60,000 annually. This figure is based on the difference in cost between the standard 3 applications of herbicide in spring and midsummer used prior to 1971 and the 3-year rotation implemented in 1971. Not included are benefits from increased weed control, safety, or reduced mowing costs.

The concept of a 3-year rotation stemmed from data summarized in Figure 7. These data are from the 1971 spraying program 1 year after spraying. The lower curve represents roads that had been sprayed in previous years and contained mostly resistant species. The upper curve represents roads that had not been sprayed recently and contained mostly species susceptible to 2,4-D.

A pattern of weed control emerged as follows: The optimum weed density for maximum effectiveness was about 150,000 weeds per acre. With this weed density, control approached 90 percent on roads not previously sprayed. As the weed density decreased or increased from this value, effectiveness of weed control decreased. With roads having 25,000 weeds per acre or less, treatment effectiveness ranged from 0 to 30 percent. These roads were not "weedy" to begin with, contained mostly species resistant to 2,4-D, and should never have been sprayed in a contract program.

Based on these data and results from experimental plots, a 3-year spraying rotation was established for the entire state. The roads were divided into 3 groups of about 4,000 linear miles (24,000 acres) each. Group A was the Interstate System. Groups B and C were composed of roads of the state highway system. Roads of group A received a fall-spring 2,4-D cycle in 1972-73 (Figures 2 and 4). Roads of group B received a fall-spring cycle in 1973-74, and roads of group C will receive a fall-spring cycle in 1974-75. In the fall of 1975, the cycle will be repeated beginning with roads in group A. The program is computerized to reduce administrative costs. Marion Bugh, Landscape Supervisor of the Indiana Highway Commission, and his staff did an excellent job in setting up the contracts so that each year approximately one-third of the state is sprayed, with maximum efficiency for both the state and the individual contractors.

We anticipate that by the fall of 1975 roads in group A will have weed densities in the range of 75,000 to 150,000 weeds per acre so that the cycle will be repeated. One year after spraying, the weed density is about 15,000 weeds per acre. To spray these roads then would be a waste of time and money. Two years after spraying, we forecast the weed density to be 30,000 to 50,000 weeds per acre. At best, we could expect 50 percent control to reduce the population back to 15,000 weeds per acre. By 3 years, when the weed population has again reached the level of 75,000 to 150,000 weeds per acre, the roads will be resprayed.

OTHER HERBICIDE MIXTURES

Some experimental herbicide mixtures give a weed-free turf for 3 years following a single fall application. What about 2,4-D-resistant weed species? Will they eventually

Figure 7. Relationship between weed density in thousands of plants per acre and percent total weed kill for the fall-spring 2,4-D application cycle described in Table 1. The upper solid curve is for roads previously unsprayed, which contained mostly 2,4-D susceptible species. The lower dotted curve is for roads that had been sprayed within the past 2 years and contained mostly 2,4-D resistant species. Each point represents data from a different highway within a single district. The different symbols show results from the commercial applicators involved in the 1971-72 spraying program. Evaluations were in late August, September, and early October 1972, 1 year following the fall application.

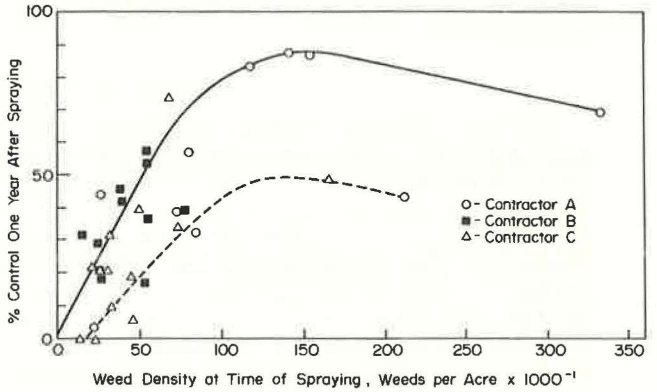


Figure 8. Appearance of test plots in a 3-year evaluation prior to spraying in early August 1970. Wild carrot was especially abundant and unsightly.

Figure 9. Same test area as shown in Figure 1 photographed in July 1972, approximately 2 years after spraying with varying rates of the picloram-2, 4-D combination herbicide. Even though the area was recently mowed, growth of wild carrot, buckhorn plantain, and other weeds was evident in the control plot in the foreground. The treated plots remained free of weeds.

increase to the point that 2,4-D spraying becomes ineffective? We do not have answers to these questions but are exploring new and more potent herbicide mixtures for use along Indiana roadsides if and when they are needed. By using more potent herbicides, we have maintained turf in a nearly weed-free condition for at least 3 years following a single fall application (Figures 8-10) with no injury to grass or trees. Therefore, only 1 application every 3 years is required. Even the spring application is eliminated, an additional cost-saving feature.

One of these herbicide mixtures, currently under intensive investigation, consists of a combination of 3 parts of picloram (trade name Tordon) and 1 part of 2,4-D, plus an agent to control drift. The picloram-2,4-D combination is a potent herbicide for control of a wide range of broad-leaved herbaceous and woody roadside vegetation. Difficult-to-control perennial species such as common milkweed and Canadian thistle are especially susceptible to picloram. A significant portion of the picloram necessary for control of these species is replaced by the less-expensive phenoxy herbicides such as 2,4-D without reducing the overall effectiveness of the treatment (1, 2).

With the objective of testing the possibility of a 3-year spraying rotation in which 1 herbicide treatment would keep the roadsides free of weeds for the entire 3-year period, plots were established in the falls of 1970, 1971, 1972, and 1973 to evaluate the lasting effectiveness of combination treatments and in 1972 and 1973 to evaluate environmental safety. Triplicate plots were sprayed at rates of ½, 1, 1½, and 2 lb/acre (up to 6 lb/acre in the environmental tests) in mid-August to early October. All species were 90 to 100 percent controlled the first season by applications at rates of 1 lb/acre or greater (Tables 3 and 4). Evaluations 1 and 2 years later indicated lasting control for most species except a few summer annuals such as nodding spurge that germinate from seed in early summer and are not especially objectionable. For all practical purposes, the sprayed plots were still weed-free (Figures 9 and 10) at the 2 lb/acre rate 3 years after spraying for the experiment begun in 1970.

In the 1972 study, the environmental safety of picloram was evaluated. Based on extensive laboratory, greenhouse, and field testing (1, 2, 3, 4), a 3:1 ratio of picloram plus 2,4-D was selected for initial evaluation under roadside conditions at a rate of 1 lb/acre of total herbicide (¾ lb picloram plus ¼ lb 2,4-D amine). The application, in early October, used truck-mounted equipment supplied by Chemitrol, Indianapolis. The formulation, designated M-3766, was provided by Dow Chemical Company, Midland, Michigan, according to our specifications. It contained 1½ lb active ingredient picloram plus ½ lb active ingredient 2,4-D per gallon as the triisopropanolamine salts. Applications were at rates of ½, 1, 2, and 6 lb active ingredient per acre. Endrift, a commercially available drift-reducing agent manufactured by Nalco Chemical Company, was included at the rate of 1 quart per 100 gallons of spray in all applications. Drift tests showed a 40 to 50 percent reduction in the amount of herbicide reaching nontarget areas using this material. Included in the test were roadside plantings, ornamental plantings, hardwood forest, conifers, a flowing stream, and cropland. Species composition was determined and soil and water samples were collected prior to and after spraying. At 1 lb/acre, M-3766 gave 90+ percent control of all weed species (Table 4; Figure 5).

Using a sensitive biological assay procedure developed under this project, testing of water samples collected from the stream running through one of the test sites revealed no detectable herbicide entering the water from drift at the time of spraying. Tests of soil samples showed that the herbicide remained on the target area except for 1 situation at the 6 lb/acre rate where the sprayed roadside was higher than the adjacent field and where the drainage ditch channeled soil and water from approximately 1 mile of road directly into 1 spot of the field. Here, herbicide entered the field and caused slight injury to soybeans. Examination of roadside plantings, native vegetation, and fruit trees in an orchard adjacent to the sprayed roadside revealed no damage to species not oversprayed directly.

A similar test, although not as extensive, was established in the spring of 1973, with M-3766 applied at a rate of 2 lb/acre. In this test, basswood trees adjacent to the sprayed roadside were killed. Other tree species showed only minor injury symptoms, including those in which root systems were directly oversprayed, and all survived. In

Table 3. Effectiveness of fall application of picloram plus 2,4-D mixtures on control of roadside weeds in the season following application.

Weed Species	Control	Rate of Application of Total Herbicide Mixture			
		½ lb/acre	1 lb/acre	1½ lb/acre	2 lb/acre
Wild carrot	16	2	0	0	0
Buckhorn plantain	119	1	0	0	0
Rough cinquefoil	6	0	0	0	0
Common milkweed	3	0	0	0	0
Wild parsnip	1	0	0	0	0
Broadleaf plantain	8	0	0	0	0
Whorled milkweed	3	0	0	0	0
Black medic	12	0	0	0	0
White clover	10	0	0	0	0
Yellow woodsorrel	5	0	0	0	0
Nodding spurge	29	9	15	9	9
Composite family (goldenrod, asters, etc.)	6	0	0	0	0

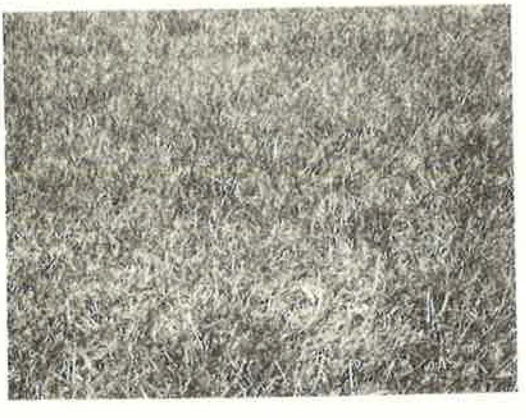
Note: Treatments (3 parts picloram, 1 part 2,4-D) were applied in mid-August 1970 and counts were taken October 7, 1971. Data are given in plants per 100 ft^2.

Table 4. Effectiveness of fall application of picloram plus 2,4-D mixture on control of roadside weeds.

Weed Species	Control	Rate of Application		
		½ lb/acre	1 lb/acre	2 lb/acre
Plantain	19,575	0	0	0
Dandelion	8,260	435	210	0
Wild carrot	6,520	0	0	0
Clovers	3,480	0	0	0
Curled dock	960	0	0	0
Common thistle	1,300	135	95	0
Other composites	4,350	0	0	0
Other weeds	6,000	450	0	0

Note: Treatments (3 parts picloram plus 1 part 2,4-D) were applied in early October 1972 with commercial truck-mounted equipment and counts were taken in May 1973. Data are given in plants per acre.

Figure 10. Close-up view of the treated area from tests described in Figures 8 and 9 photographed in July 1973, approximately 3 years after spraying. The plots remained free of weeds for a minimum of 3 years following the single application of herbicide.



spite of heavy rains, soil movement of no more than 3 ft was experienced. However, picloram will not be recommended for use in spring or summer applications for general roadside weed control because of possible crop injury.

Picloram, which has a mode of action similar to that of 2,4-D (5), has proved non-toxic in pure form (3, 4). Laboratory tests of the formulated material are nearing completion and show no injury to fish or algae that might result from normal use practices.

A third herbicide combination involving dicamba (Banvel) plus 2,4-D also looks promising in preliminary tests to control 2,4-D-resistant species. This material is not as effective as the picloram plus 2,4-D combination but is expected to provide an even greater margin of environmental safety.

BENEFIT FROM REDUCED MOWING COSTS

Effective programs of herbicide treatment reduce the number of required roadside mowings. With the weed control provided by the 3-year rotation (with either 2,4-D amine alone or with the more potent mixtures), 3-cycle mowing (once in late spring, once in midsummer, and once in late summer or early fall) is sufficient. The reduction in the number of mowing cycles (from 4 or 5 to 3) produces an additional $100,000 annual cost saving to the program (based on figures provided by Marion Bugh).

Further reductions in mowing cycles (less than 3) may not be feasible. One-cycle mowing, or even 2-cycle mowing, if scheduled early, leaves too much growth in the fall for effective applications of herbicides. If scheduled later, the tall grass that is mowed and not raked smothers the underlying sod. Large bare spots subject to erosion are the result. It may prove more advantageous to not mow at all than to mow only once or twice.

CONCLUSION

In summary, rights-of-way are designed for safety and convenience. They should be kept as corridors of open turfed areas to provide the features of safety, beauty, and convenience for which they were intended. To maintain a healthy turf, maintenance of these areas by mechanical and chemical methods must continue. Our findings show new ways of providing such maintenance at low cost to the state and minimum danger to the environment.

ACKNOWLEDGMENT

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