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and
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5 Reports

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Foreword

Budgeting is a basic responsibility of highway department officials, and it is a significant area of concern for maintenance engineers. Budget officers and maintenance engineers will be interested in this RECORD.

Performance budgeting, i.e., budgeting measures related to work requirements for operational functions, is explored in a paper by Helland who describes the process by which essential elements, such as work load, maintenance levels, resource requirements, records and reports, management planning, evaluation, and control, were brought together in a management system for the Utah Department of Highways. The report is noteworthy because the Utah Department of Highways has become one of the first state highway departments in the United States to institute such a system for maintenance budgeting.

Shortened versions of papers by Leigh and Delp illustrate the use of management information systems in planning and controlling pavement maintenance operations. Both authors emphasize use of resurfacing contracts as a way of minimizing total maintenance costs by leveling the maintenance work load through the year. Both of them recommend scheduling pavement resurfacings on a regular time cycle. Leigh offers some interesting cost comparisons and mentions Virginia's management information system. Delp lists the complement of crew and equipment found best for maintenance of state highways in Kansas. Although he does not tabulate the data, the complement represents the conclusions derived from a number of research studies and cost analyses extending over a period of several years.

Some systems for snow and ice detection have a demonstrated ability to predict pavement icing 2 hours in advance with 96 percent accuracy. Some other more inexpensive systems have been right only 20 percent of the time. Other systems fall between these extremes in both initial cost and reliability; one such system is reported on by Ciemochowski. Ice-detector systems may include warning signs, warning devices in maintenance garages or superintendents' homes, and may even activate pavement heating coils or salt spreaders. Smiley points out in his discussion of Ciemochowski's paper that accuracy is dependent on a number of factors other than a simple monitoring of temperature and humidity. He comments on the effect of the presence of pollutants on the freezing point of water and the accuracy of the reporting devices. Other investigators have reported different factors that affect the ability of detectors to provide useful driver information. Detectors are placed at times near a bridge curb where a windrow of snow is developed by snowplows, wind currents are not constant, and temperatures vary greatly; a detector placed in one corner of a bridge, for example, may not report the presence of ice at the other corner of the bridge.

Because of limitations of publication space, sections of Willing-Denton's paper relating to historical information, durability of pavements subjected to action of salt, salt storage recommendations, and corrosion were deleted. However, most of the information published in this RECORD is available in noncompiled form elsewhere. Even so, the paper brings together, in helpful and readable form, the results of studies in Great Britain extending over a period of more than 15 years. This paper offers much factual information on rates of salt application, guides to practice, and equipment specifications.

Contents

Performance Budgeting for Maintenance: A Budget Based on Quality, Quantity, and Productivity Standards

HENRY C. HELLAND, Utah Department of Highways

•TRADITIONALLY, highway maintenance in Utah, as in other state highway departments, has been budgeted on the basis of miles or lane-miles of highway and past experience, and allocations are made under the traditional budget to districts and subdistricts (in Utah, these are called stations) in terms of money for the reasources of labor, equipment, materials, and contractual services. Allocations under the performance budget are made in a similar manner both in terms of the kinds of resources and the districts and subdistricts.

The difference comes in how we measure the needs for resources. Under performance budgeting, we now define the maintenance requirements in terms of activities, not just maintenance. It is now a conglomerate of pothole patching, roadside mowing, blading shoulders, plowing snow, and other activities.

We determine how much of each of these activities will have to be performed in each maintenance station. We determine how much resources—labor, equipment, and materials—will be required for each of these activities. And, the performance budget becomes the total of the resources required for all of the activities in each station, in each district, and in the state as a whole. So, the big difference is that the performance budget is built up activity by activity. Further, in administering or controlling the budget, we now can provide managers with activity-related measures and not just fiscal measures. We budget performance of work activities and exercise management control over maintenance activities.

ESTABLISHING A PERFORMANCE BUDGETING SYSTEM

The introduction of a performance budgeting system in Utah was started in April, 1967. The basic foundation for the system was provided by the establishment of maintenance policies for a long-range plan, maintenance programs, maintenance performance standards, and a maintenance reporting system. These were formally approved by the Utah State Road Commission (see Appendix). A target date for introduction of the performance budgeting system was set for July 1, 1969. With the recognition of a possible need for advance decisions by the road commission, a schedule was established for an interim report to the road commission in December 1968. This report has been made and the commission is now considering alternative actions directed toward implementation of the system.

The principal steps that have been taken by the Utah Department of Highways in development of the system can be summarized as follows:

1. Work activities—the definition of maintenance work activities, establishment of units for work measurement, and definition of types of roads for classification by maintenance characteristic.
2. Maintenance feature inventory—the conduct and compilation of an inventory of the maintenance features or characteristics on the highway system that relate to amounts of maintenance work required.

Paper sponsored by Committee on Maintenance Management.

3. Standards—the development of standards for each road type (a) defining level of service, (b) defining average annual quantities of work needed, (c) establishing standard methods and procedures for work performance, and (d) establishing expected rates of accomplishment.
4. Reporting—the development of a work-reporting system that permits compilation of valid data on resources used and accomplishment attained and provides meaningful summaries of information to management.
5. Maintenance program—the development of an annual maintenance program showing planned work and resource requirements for individual management units, based on established standards and current road inventory.
6. Scheduling and control—the development of procedures for work planning, scheduling, and controlling by district and operating-level supervisors.

Those elements in the development of a maintenance performance budget that appear particularly significant are discussed in the following sections.

DEVELOPING STANDARDS

The performance budget system requires that we set several kinds of standards. First, we need a level of service or quality standard so that there is uniformity throughout the state and that there is an adequate level of maintenance. Second, we need to convert the quality standard into meaningful quantities of work activities. These are called quantity standards. Third, we need productivity standards. These define how work is to be done, the staffing required to do it, and the productivity rate that should be attained.

The standards in Utah have been established by a standards panel assisted by the maintenance project staff. We think that the work of the standards panel has been a prime contribution to the system. The panel has met for a two-day work session each month, and has reviewed, evaluated, and revised standards for more than 30 activities.

Because of the importance of the standards, an example is presented to illustrate what the standards do. The complete standard for the semiannual-annual mowing activity, shown in Figure 1, is broken down into the following elements: responsibility, definition, quality and workmanship, scheduling considerations, methods and procedures, crew arrangements, and expected performance. The mowing standard illustrates how guidance is provided to the foreman—what, when, and how much mowing—and also how quantity values are provided for development of the budget.

The responsibility statement indicates who is responsible for decision with regard to this activity. In this instance, it is the station foreman's (first-line supervisor) job to decide when and where this activity is to be performed. The decision is controlled, however, by subsequent requirements of the standard. For some activities, the responsibility for decision may be placed on the district maintenance supervisor. The definition gives a description of the activity and provides guidance as to the general scope and purpose of the activity. Quality and workmanship define, in this case, what is considered adequate performance in terms of mowing frequency, mowing width, and vegetation height. Scheduling guidance is provided to the foreman in terms of which months and on what road classes the semiannual-annual mowing activity is to be performed.

Method and procedure indicate specified ways of performing this mowing operation. Relevant comments here pertain to the effective use of bat-wing and single-swath mowing units. Crew arrangement gives the typical numbers and types of men and equipment to be used for the particular work. Expected performance indicates what the foreman should expect in the way of daily production and productivity under normal circumstances with the use of the specified method and procedure. These kinds of standards set the quantities for the principal work activities on which the performance budget is based.

USING FIXED ACTIVITIES TO DETERMINE MANPOWER FOR BUDGET

In the development of the maintenance work program and the budget, activities are classified as either fixed, semifixed, or variable. Fixed maintenance work activities

PERFORMANCE STANDARD
UTAH STATE DEPARTMENT OF HIGHWAYS
OFFICE OF MAINTENANCE
SEPTEMBER 1, 1968

ACTIVITY 141-100

SEMI-ANNUAL/ANNUAL MOWING

RESPONSIBILITY - Station Foreman

DEFINITION - The specifically planned, scheduled and controlled Semi-Annual or Annual mowing that extends as far towards the right-of-way lines as required for purposes of controlling weeds, eliminating a snow drift line, reducing the likelihood of concealing animals and maintaining roadside appearance.

QUALITY AND WORKMANSHIP - This mowing activity is performed in accordance with the following guidelines:

- The Semi-Annual/Annual mowing will:

  1. Extend a minimum of 20 feet from the pavement edge, where a mowable right-of-way occurs; and
  2. Extend beyond 20 feet only where required to control weeds, eliminate a snow drift line or reduce the likelihood of concealing animals.

- Vegetation is not to be mowed closer than 5".

- This mowing activity is to represent the first and the last mowings (Semi-Annual) of the season on all roads except Low, Gravel or Unimproved (Classes 5, 6 or 7) which receive only one mowing (Annual) per season.

SCHEDULING CONSIDERATIONS - Semi-Annual/Annual Mowing is performed in accordance with the "X" in the schedule below without regard to a vegetation height requirement.

	INTERSTATE	HIGH CLASS	INTERMEDIATE CLASS	LOW CLASS, GRAVEL AND UNIMPROVED
JUNE	X	X	X	
JULY				
AUGUST				X
SEPTEMBER				
OCTOBER	X	X	X	

The June (Semi-Annual) mowing is intended to coincide with the end of the rapid spring growth cycle in order to cut undesirable vegetation prior to the seed stage and to improve summer roadside appearance. Adjustments are to be made when unusually wet or dry years make adherence to the June scheduled cut impractical.

Figure 1. Performance standard for semi-annual/annual mowing.

are ones that must be performed during specific times or periods of the year because of temperature (such as seal coating), seasonal (such as mowing), or functional (such as supervision) considerations. Semifixed activities are those that must be performed during a certain period of the year, but that can be shifted within the months as required for workload leveling. Activities in this category include grading roads, grading shoulders, and semiannual drainage maintenance. Variable activities are those that can be performed virtually anytime during the year because there are no general constraints. Included in this group are activities such as fence repair, annual litter pick-up, and brush cutting.

PERFORMANCE STANDARD
UTAH STATE DEPARTMENT OF HIGHWAYS
OFFICE OF MAINTENANCE
SEPTEMBER 1, 1968

ACTIVITY 141-100

SEMI-ANNUAL/ANNUAL MOWING
CONT.........

The October (Semi-Annual) mowing is intended to eliminate snow drift lines and improve winter-spring roadside appearance.

The August (Annual) mowing, the only mowing provided Low Class, Gravel and Unimproved roads, is intended to eliminate snow drift lines and improve Winter-Spring roadside appearance.

METHOD AND PROCEDURE - Mowing is machine paced, and therefore, the most efficient operations are those which depend on each mower working independently. Bat-wing mowers are most effectively used to mow wide swaths and make a minimum of turning and movements. Five foot single unit mowers should be used with bat-wing when required for clean-up.

CREW ARRANGEMENT - Crew arrangements should vary depending upon whether the operation includes the use of a bat-wing mower or not.

OPERATIONS WITH BAT-WING AND SINGLE UNIT MOWER		OPERATIONS WITH SINGLE UNIT MOWER ONLY	
2 Men		1 Man	
1 Mower	38-01	1 Mower	38-01
1 Mower	38-02	1 Tractor	04-05
2 Tractors	04-05		

EXPECTED PERFORMANCE - The following performance can be expected under normal circumstances:

Daily Production:

Single Unit Mower	6.3 - 9.3 acres
Bat-Wing and Single Unit Mower	25.0 - 37.4 acres

Productivity:

Single Unit Mower	0.9 - 1.3 man hours/acre
Bat-Wing and Single Unit Mower	0.4 - 0.6 man hours/acre

Figure 1. (continued).

By distributing the man-hours associated with the fixed, semifixed, and variable activities in accordance with the respective constraints and with an objective of building as level a work load as possible, we determined manpower requirements. Figures 2 and 3 show for two of Utah's districts the resulting manpower requirements as determined by the accumulation of needs for fixed, semifixed, and variable activities. The northern district has 2,307 lane-miles, with approximately 50 percent of the lane mileage at higher elevations, contains the metropolitan area of Ogden, and has an annual precipitation of 16 to 18 in. Analysis of this district's work load indicated a peak fixed activity staffing requirement of 87 for July. The addition of the semifixed and variable requirements during off-peak months resulted in a level need for 87 men for the period from April through November. Because of our ability to level out the work load in all but four winter months, we did not need to hire temporary summer workers.

The southwestern district has 2,358 lane-miles, with approximately 10 percent of the lane mileage at higher elevations, has no large metropolitan areas, and has an

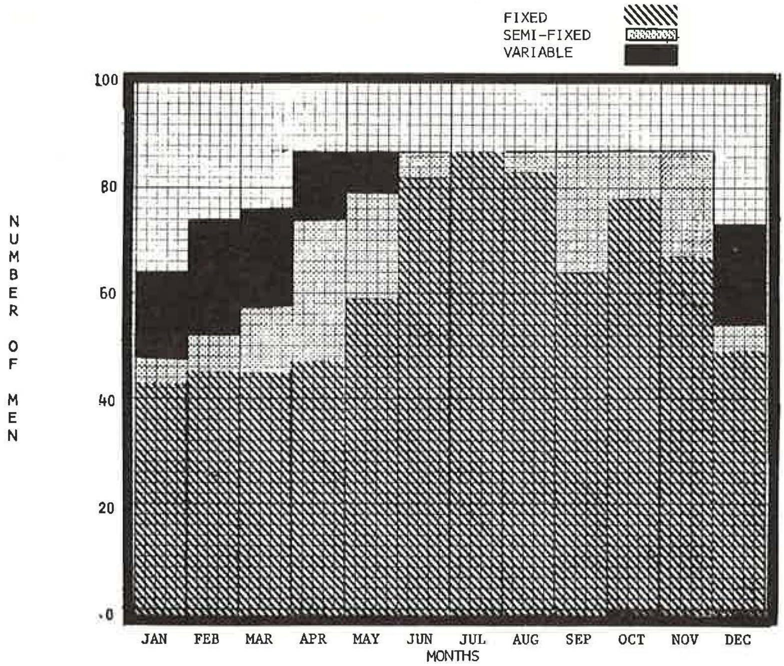


Figure 2. Manpower requirements for maintenance in a northern district.

annual precipitation of 8 to 10 in. Here again our analysis indicated a peak staffing requirement of 81 for fixed activities during July. However, because of the more temperate winter months and limited areas where snow cover exists, a substantially greater amount of this district's semifixed and variable work could be planned for performance during the period from December through March. Therefore, the annual work load

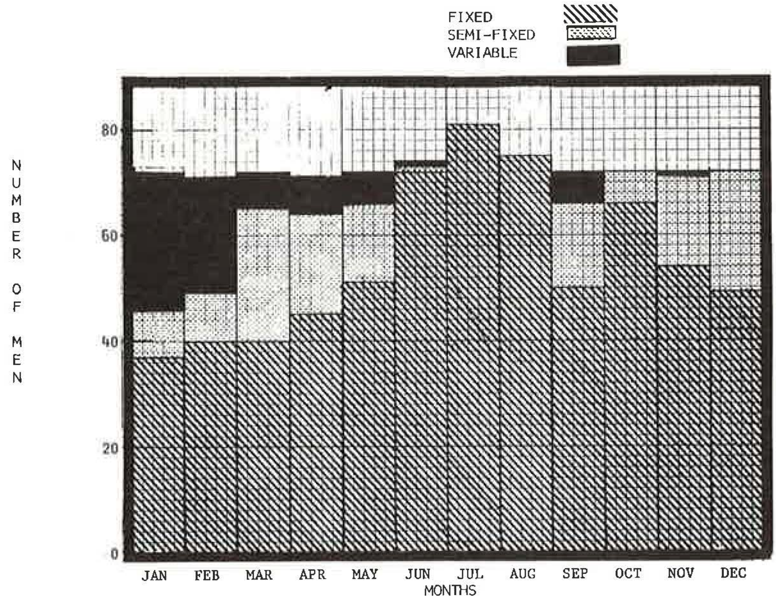


Figure 3. Manpower requirements for maintenance in a southwestern district.

could be handled with level staffing requirements for all but the summer months of June, July, and August, and a permanent staffing level of 73 was established to be supplemented by 8 temporary summer employees.

Analyses of all of the districts revealed that even though the activities performed were the same, each had its own peculiar work load composition and each demanded slightly differing staffing solutions. The analysis also revealed the inadequacy of allocating resources solely on the basis of road or lane-miles. The pursuit of performance budgeting has brought us a long way toward developing an objective approach to staffing requirements. However, alternative staffing solutions that will be examined in the years ahead include the potential reduction of permanent staffing levels through the use of greater amounts of planned overtime, and the reduction of permanent staffing levels by creating an accentuated summer peak that could be performed by temporary employees hired seasonally.

TRANSITION TO FULL IMPLEMENTATION OF THE SYSTEM

We now have a basis for a performance budget on which the maintenance work program can be based for the fiscal year beginning July 1, 1969. We have standards for the principal work activities on which the budget is based and by which field supervisors can schedule work. We have designed a specific work scheduling and reporting system to ensure control in accordance with the budget. We have tested the system extensively. All maintenance stations are currently scheduling and reporting as required by the system.

The critical problem now is to provide adjustments in staffing to fit the manpower resources required for the new system. Figure 4 shows our goal in terms of expenditures for maintenance. Additional funding will be required during the implementation

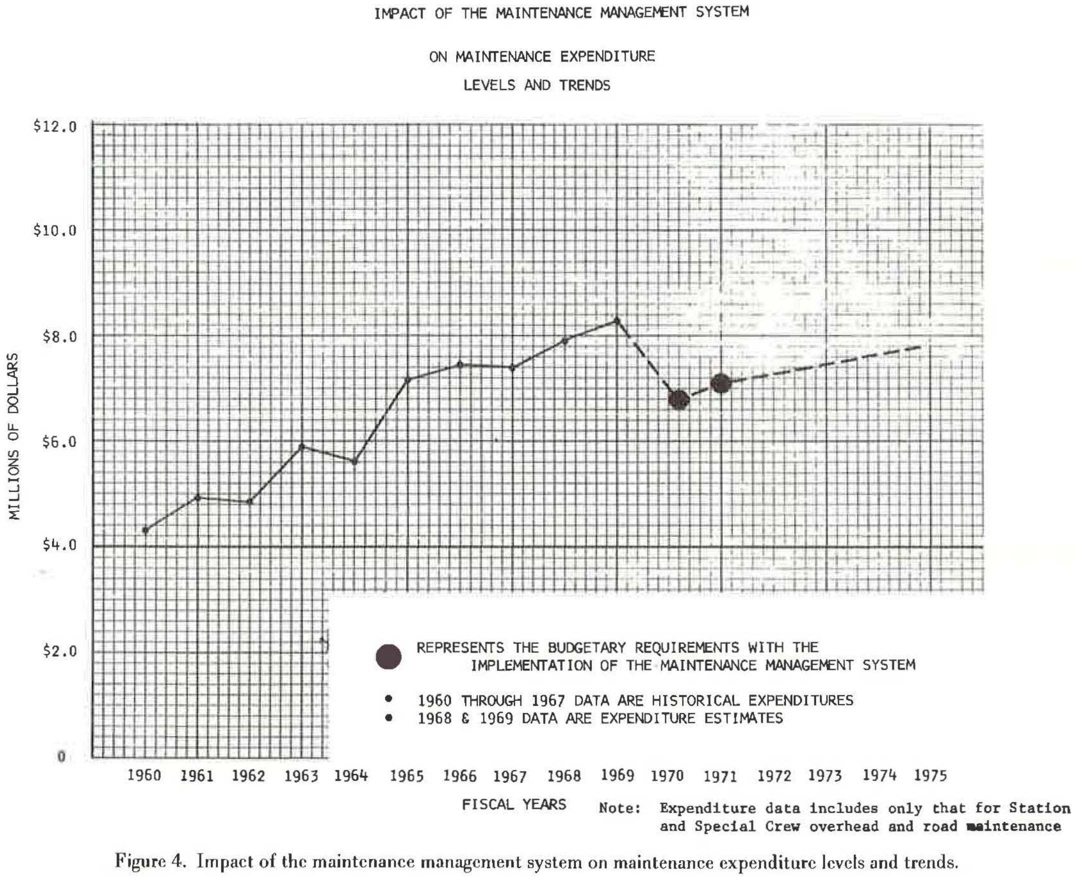


Figure 4. Impact of the maintenance management system on maintenance expenditure levels and trends.

TABLE 1

NUMBER OF MAN-MONTHS, AT CURRENT STAFFING LEVELS, RELEASED FOR NONMAINTENANCE ACTIVITY—DURING FISCAL YEARS 1970 AND 1971

District	Man-Months Available			Total Man-Months Required for Maintenance Workload		Total Man-Months Released	
	Permanent Employee[a]	Summer Employee[b]	Total	1970	1971	1970	1971
1	1,287	120	1,407	983	1,002	424	405
2	1,836	162	1,998	1,045	1,052	953	946
3	744	102	846	741	741	105	105
4	1,008	105	1,113	727	736	386	377
5	876	39	915	876	876	39	39
6	1,284	60	1,344	1,025	1,027	319	317
Total			7,623	5,397	5,434	2,226	2,189

[a]Based on October 1, 1968, staffing levels.
[b]Based on the number of temporary employees during the summer of 1968.

TABLE 2

ESTIMATED MONTH AND YEAR OF ALIGNMENT OF AVAILABLE AND REQUIRED MANPOWER UNDER A POLICY OF ATTRITION WITH NO REPLACEMENTS

District	Current Staff[a]	Annual Attrition Rate (percent)	Staff by Fiscal Year				Month of Alignment
			1969	1970	1971	1972	
1	107	20	97	88			January
2	153	20	138	110	97		March
4	84	10	80	72	65	61	February
6	107	10	100	90	86		December

[a]Number of permanent employees as of October 1, 1968, assumes implementation of attrition policy January 1, 1969.

period for training and manpower adjustments. Table 1 gives the manpower adjustments needed to reach the potential of the performance budget. In districts 3 and 5, the adjustment is small and readily attainable. In the other three districts, the adjustment is sizable.

Consideration is naturally given to attrition as a means of attaining adjustment in staffing. Table 2 gives a projection based on current personnel turnover rates within the four districts where adjustments are needed. It will be noted that alignment through attrition alone is not achieved until February 1972. From a practical standpoint some of the positions vacated will require replacement. This would contribute to a delayed alignment. Because of this and our desire to attain alignment as soon as possible, we are considering a combined use of attrition and transfers.

As this is being written, a decision has not been made as to how the transition to the new system will be fully effected. However, we hope that the transition can be accomplished by July 1, 1970.

Appendix

LONG-RANGE MAINTENANCE PLAN

POLICY: Forecasts of maintenance requirements will be projected over a period of years to conform with the long-range plan for highway construction and the financing thereof to provide estimates of long-term requirements for manpower, equipment, materials and money, as well as plant facilities.

SCOPE: The Long-Range Maintenance Plan will constitute the objectives of the maintenance function of the Utah State Department of Highways which are to preserve and operate the State Highway System in such a manner that:

1. the investment in roads, bridges and appurtenances is preserved,
2. comfort, convenience, economies and safety are afforded the motorists and the public, and,
3. the necessary expenditure of resources is accomplished with continuing emphasis on economy.

MAINTENANCE PROGRAMS

POLICY: Annual maintenance work programs will be established for districts and sheds based on the mileages of the different classifications of highways and roads and on the quantity and productivity standards for maintenance work activities.

These annual maintenance programs will be prepared by the Office of Maintenance, reviewed by the State Highway Engineer and the Director of Highways and approved biannually by the Road Commission.

SCOPE: When annual maintenance work programs are approved they will become the basis for allocating resources to the management units responsible for carrying out the work in the field.

MAINTENANCE PERFORMANCE STANDARDS

POLICY: To assure the attainment of the desired level of maintenance; to provide uniformity throughout the State; and to give quantitative bases on which to plan and carry out the maintenance program, performance standards will be established for:

Quality - To set the level of service and a gauge for work requirements for maintenance activities.

Quantity - To reflect the work requirement for different activities in terms of practical and significant measurements, such as tons of patching, acres of mowing, etc.

Productivity - To establish methods of doing work and the productivity to be expected in terms such as: man-hours per ton of patching materials, etc.

SCOPE: Approved maintenance standards will serve as guides in the development and maintenance of the Long-Range Maintenance Plan, Maintenance Programs, budget allocations and the state-wide application of efficient and economical maintenance methods and procedures.

MAINTENANCE REPORTING SYSTEM

POLICY: A system of maintenance reporting will be established to provide records of work accomplished in terms directly relatable to work programs. Summarizations of report data will be made available to maintenance management personnel at all levels, from Commission to Shed Foremen, in form best designed to serve their needs.

SCOPE: Reports to field operating personnel will be used as guides to improving performance and for reviewing performance standards.

Reports to top level management will relate performance to planned work for the year by Districts. These reports will be accomplished by Office of Maintenance analysis and a summary of actions taken or to be taken.

Reports to top management will also present trends in performance standard values and other significant statistics demonstrating improvement in performance.

Changing Character of Pavement Maintenance

C. O. LEIGH, Virginia Department of Highways

•THE COST PER MILE of routine surface maintenance on the hard-surfaced secondary roads in Virginia has been decreasing in recent years and, as a result, the total cost per mile of surface maintenance on these roads has remained almost the same for the past 5 years. This paper examines some of the changes in policies and procedures that have contributed to the cost trends, and discusses the implications of the cost trends to management in making decisions regarding surface maintenance. In this discussion, the terms ordinary maintenance, maintenance replacement, and total surface maintenance are defined in terms of surface maintenance as follows. Ordinary maintenance is routine surface maintenance and includes skin- or seal-type patching, filling potholes, and scarifying and re-treating short sections of under 1,000 ft in length. Maintenance replacement is the resurfacing of a road where the new surface does not exceed the depth of the original treatment; it includes seal treatments, mixed-in-place treatments, drag treatments, and bituminous concrete treatments. Total surface maintenance is the sum of ordinary maintenance and maintenance replacements.

Figure 1 shows the trends in cost per mile for ordinary maintenance, maintenance replacement, and total surface maintenance for fiscal years 1953-1954 through 1967-1968. (Data are not available for costs prior to 1953.) The significant reduction in costs for the fiscal year 1959-1960 was brought about by the recession in the late 1950's and should not be considered typical of the trend in expenditures. The trends shown in Figure 1 are based on actual dollar costs. Figure 2 shows the costs adjusted to the 1957-1959 base period.

In 1959, we established as a goal the resurfacing of approximately 20 to 25 percent of the secondary mileage each year. Approximately 95 percent of the resurfacing on the secondary system is a chip seal, which at base-year prices costs approximately $1,000 per mile. From fiscal year 1960-1961 to date, we have been resealing approximately 20 percent of our hard-surfaced mileage annually. At the same time that we began to seal 20 percent of the secondary mileage, we began to get a decrease in the amount spent per mile for ordinary maintenance.

The apparent relationship between the amount of maintenance replacement work performed each year and the amount of the required ordinary maintenance must be studied further to determine the point of maximum economy in surface maintenance that can be achieved for a given service level and that can meet the overall objectives of the total maintenance program at the same time. For instance, it is possible to achieve significant reduction in the ordinary maintenance costs by increasing the frequency of re-treatments. However, as the frequency of re-treatment passes a certain point, total maintenance costs begin to increase.

The determination of the point of maximum economy is not a one-time analysis, but is something that must be revised almost every year. Figure 1 shows that, based on actual dollars, we have had almost constant expenditures for the three costs occurring during the past 4 to 5 years. If we continue to maintain a 5-year re-treatment cycle, our total costs are going to increase in the future. Ordinary maintenance and maintenance replacement both represent the placement on a road of a certain number of tons of stone. The cost index for ordinary maintenance is increasing much faster than the cost index for maintenance replacement, which represents mostly contract work. We can keep total surface costs from increasing by placing fewer tons of stone on roads

Paper sponsored by Committee on Maintenance Management.

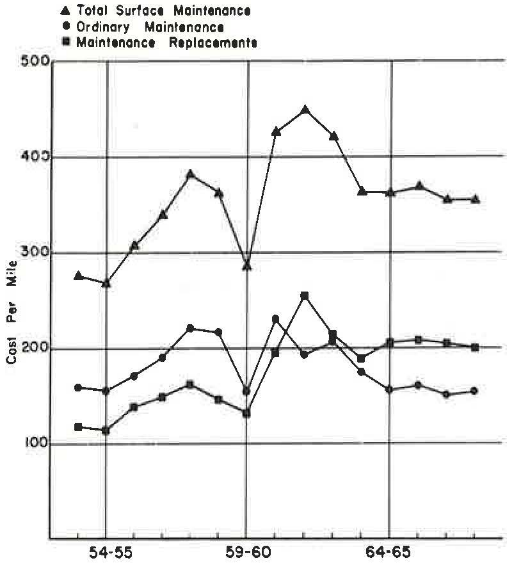


Figure 1. Cost of surface maintenance of hard-surfaced roads in secondary system.

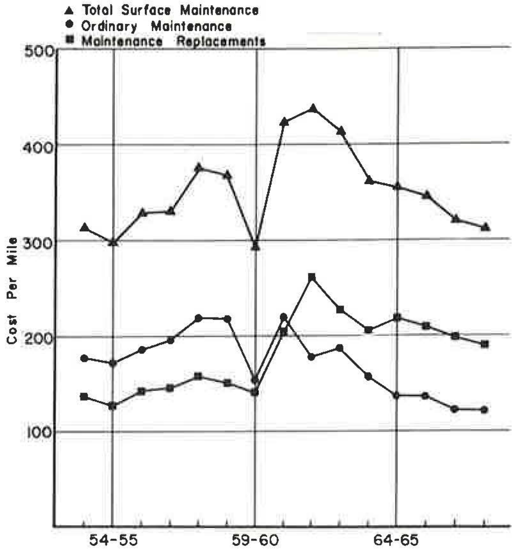


Figure 2. Adjusted cost of surface maintenance of hard-surfaced roads in secondary system.

by ordinary maintenance, and more by contracting and by increasing the efficiency of ordinary maintenance. Determining the point of maximum economy or a range of values will necessitate additional collection of data because our historical records are of dollar costs that have been influenced by efficiency of maintenance crews and field decisions that do not conform to policy. In addition, the point of maximum economy will also vary by geographic regions.

There are two counties, A and B, that illustrate the problem. Figure 3 shows, for county A that is performing somewhat better than the state averages, the maintenance replacement and total maintenance costs as a 3-year moving average. This was done because, in our contracting and accounting system, it frequently happens that all or a portion of 2 years of maintenance replacement costs are paid for in one fiscal year. This causes large fluctuations in annual costs and makes the trends on a chart hard to see. When the decision was made to re-treat approximately 25 percent of our mileage each year, county A attempted to comply. It has treated an average of better than 20 percent of its hard-surfaced mileage each year since fiscal year 1958-1959. This, coupled with the increase in amount of re-treatments, has decreased the cost per mile of ordinary maintenance below that of the state average.

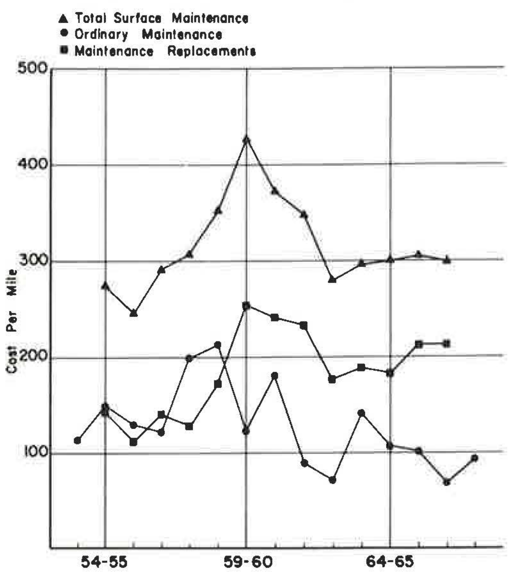


Figure 3. Cost of surface maintenance of hard-surfaced roads in county A.

Figure 4 shows that trends in county B are quite different from those in county A and the state average. The maintenance replacement and total maintenance costs are shown as a 3-year moving average similar to that in Figure 3. The amount

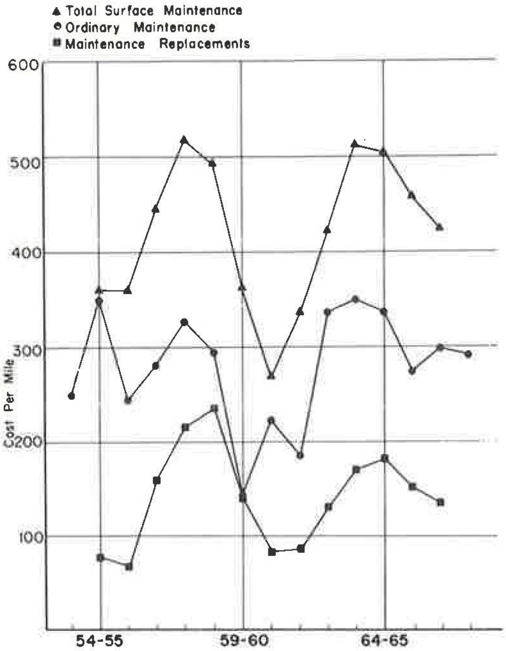


Figure 4. Cost of surface maintenance of hard-surfaced roads in county B.

spent per mile for resurfacing has been very erratic through the years, while there has been less change in the amount spent for routine maintenance. We might assume that the high rate of routine maintenance reflects the low and erratic amount spent for resurfacing. The amount of resurfacing is only part of the problem, however. Performance data indicate that it costs county B approximately 50 percent more than it costs county A to place a ton of patching stone.

A portion of the problem occurs in the attempt to use fiscal accounting records when trying to document management decisions and when attempting to develop guidelines for future decisions. For the past $1\frac{1}{2}$ years, we have been accumulating additional information such as the productivity of the work crews, unit cost of placing a ton of material, and the number of tons of patching material placed.

It is believed that we can develop from this information a relationship between tons of stone used for patching and the frequency of resurfacing. By applying unit costs to these two items, we can develop the relationship that is most economical and also other relationships where economy is secondary to reducing labor requirements on routine maintenance.

Construction and improved maintenance methods have undoubtedly contributed to the reduction of ordinary maintenance costs. However, we believe that resealing our roads at a frequency of 5 years has been the major factor in reducing ordinary maintenance costs. The information I have shown, although inconclusive, indicates that the relationships just mentioned do exist, and the information further points the way to continued study and analysis.

Asphaltic Pavement Patching in Kansas

LaRUE DELP, State Highway Commission of Kansas

•KANSAS initiated a general maintenance plan of operations several years ago. The purpose was to establish total mechanization and provide a machine-tooled finish on all repairs, as well as provide a well-balanced program with full productivity for the men and equipment during both summer and winter.

The plan provided for dividing each maintenance district into 3 or 4 subdistricts, each headed by a maintenance foreman. Each foreman was responsibile for maintaining everything owned by the Kansas State Highway Commission within his subdistrict. The plan provided for training the foreman and operators so that all repairs were made uniformly as to both methods and materials.

THE PLAN

The program preparation started in July 1964 and a target date of July 1, 1969, or 5 years, was set for completing all phases. Moving from unit patrol sections, with limited repair capabilities such as hand work or "pothole" work, to total mechanization, with an established quantity-quality concept, was a tremendous task. The first task was to divide the existing maintenance district into subdistricts and to program the buildings, storage yards, equipment, and personnel for each. The subdistrict was to become the basic maintenance unit, and its foreman was placed under direct supervision of the district maintenance superindentent.

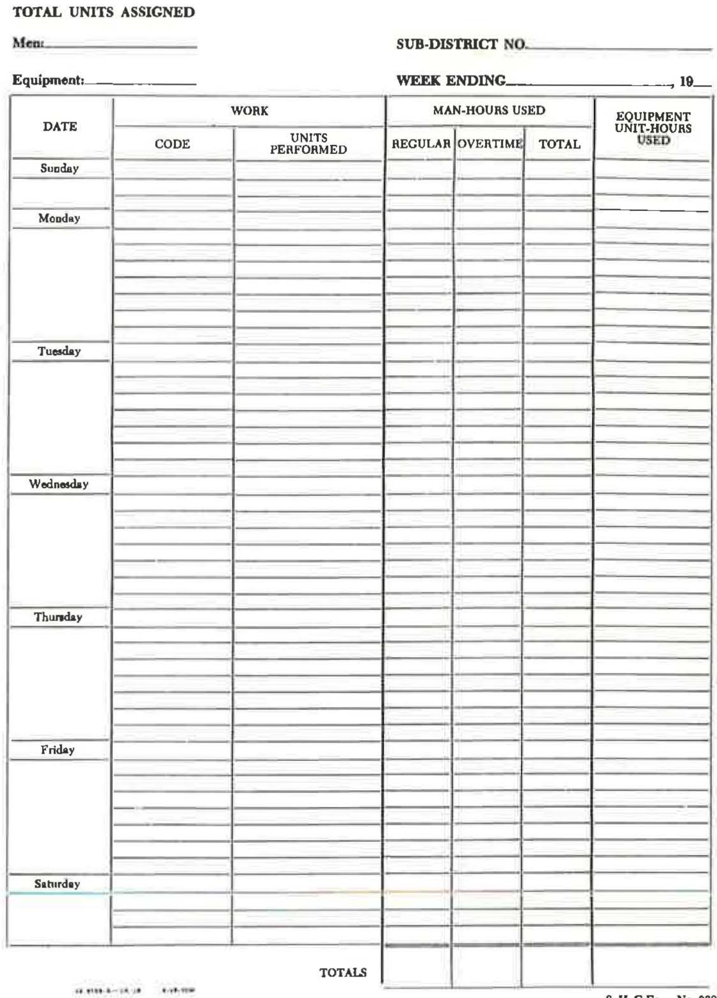
The complement of men and equipment was fixed by determining the amount required to properly care for all roadways during a major storm. Two operators were assigned to each piece of equipment. One was a first-line operator and the other was placed in training for the second shift on storm coverage. As each subdistrict was adjusted to the proper storm-coverage operations, all other phases of maintenance were adjusted to these limits. For example, throughout the summer months, the second operator became a flagman for surface repairs, an attendant in a safety rest area, or a mower operator.

Approximately 20 subdistricts were established each year throughout the 5-year period. Each contains about 100 two-lane miles of roadway or encompasses one county, but the intent is that all will have the flexibility to accommodate an increase or decrease in miles of roadway or traffic services. One foreman and 10 to 12 operators are assigned to each subdistrict, and, in general, each is assigned the following plant and equipment: maintenance office and a 4- to 6-stall garage; 3 to 5 medium-duty dump trucks equipped with a sand or chemical tailgate spreader and a front-mounted, reversible-trip snowplow; a half-ton pickup; a medium-duty motor grader, 100 hp, equipped with a V-plow; a small motor grader, 55 hp; a 600-gal self-propelled asphalt distributor; a roller, 5 to 8 tons; a loader, $^3/_4$ cu yd; and 3 to 5 mowers.

IMPLEMENTATION

To implement the operation, it was necessary to make several changes in procedures in order to maintain a balanced work load during both winter and summer months. The summer season was modified because the greatest work load occurred during this season and largely consisted of surface work with functions adaptable to contract work, such as repairs, reconstruction, overlays, and surface sealing.

Paper sponsored by Committee on Maintenance Management.



TOTAL UNITS ASSIGNED

Men: ______ SUB-DISTRICT NO. ______

Equipment: ______ WEEK ENDING ______, 19__

DATE	WORK		MAN-HOURS USED			EQUIPMENT UNIT-HOURS USED
	CODE	UNITS PERFORMED	REGULAR	OVERTIME	TOTAL	
Sunday						
Monday						
Tuesday						
Wednesday						
Thursday						
Friday						
Saturday						
		TOTALS				

S. H. C Form No. 339

Figure 1. Weekly work accomplishment report.

The next step was to determine the capability of each subdistrict for performing roadway maintenance, and this in turn set the annual contractual amounts. Each foreman submitted a weekly work accomplishment report as shown in Figure 1. The averages of data from these reports are very reliable, if various factors such as traffic volumes and weather are considered, and make possible a well-planned contract program for both overlays and resurfacing in each subdistrict well in advance of the actual work. Thus, the work load for all State Highway Commission (SHC) men and equipment can be equalized.

Most surfaces were classified by type, age, and traffic volumes, and a rigid schedule was set for repairs, overlays, and sealing in each subdistrict. Generally, light-type surfaces were set at 3 to 4 years, light bases at 4 to 5 years, and standard design base and plant-mixed surfaces at 6 to 8 years. For example, if a particular subdistrict has 60 miles of asphalt, at least 15 miles or a fourth of the light type is scheduled for extensive repairs or a light overlay by maintenance forces and then for a resurfacing seal coat by contract. A portion of the plant-mixed surfaces would be scheduled for machine seal by contract. All surface repairs are machine-laid and are full roadway widths. Of course, the concrete is repaired with a similar kind as damage occurs.

For the most part, each foreman prepares a section of roadway annually with the intent of placing a resurfacing project under contract the following season. He also plans a well-rounded program of machine seals or light overlays in lieu of surface preparation for the higher type surfaces.

The entire operation covers 15 to 20 percent of all bituminous-type surfaces annually. The repairs or leveling course are all made with similar materials; mats receive a light fog coat of emulsified asphalt to prevent raveling or deterioration until the following year's contractual seal coat is placed. All sealing is done by contract using a conventional method on the light-type surfaces and a machine or slurry seal on the higher type surfaces where traffic volumes are greater.

MANAGEMENT

Because the number of men and pieces of equipment are fixed by that required for winter maintenance, there are limitations on the volume of work that can be performed by state forces throughout the year. The additional work is done by contract during the summer months and involves resurfacing in large volumes. This provides a machine-tooled finish with quality controls.

Currently, we are using a computer to prepare a monthly work accomplishment report, shown in Figure 2, giving the work codes, work accomplished, manhours, and equipment unit hours per work unit and also averages for the state, division, and district. The monthly report is prepared from the weekly work accomplishment reports. By using averages as the normal production of a subdistrict unit, we can program in advance quantity productions for any work code. The monthly report also forms the basis for budgeting contractual work and commodities used by state forces. The program is used for quantity controls on all phases of maintenance, but it has a direct relationship to surface maintenance. It provides the tools for programming all surface work in advance of deterioration, such as potholes or surface decay. The program also eliminates expensive hand work and provides total mechanization for the machine-tooled finish.

The program has proved to be very effective during the more than 5 years it has been in effect at various stages. During this time, the materials, man-hours, and equipment

DISTRIBUTION MAINTENANCE HEADQUARTERS
DIVISION

WORK ACCOMPLISHMENT REPORT
FOR THE YEAR ENDING JULY 31, 1969
DIVISION NO. 4

(EXAMPLE)
1970 FISCAL YEAR TO DATE

WORK CODE	DESC.	UNIT	WORK UNITS YEAR ACC	WORK UNITS STATE AVE	MAN HOURS YEAR AVE	%	MAN HOURS STATE AVE	%	WORK UNIT PER MAN HOUR YEAR	WORK UNIT PER MAN HOUR STATE AVE	EQUIPMENT UNIT HOURS YEAR ACC	%	EQUIPMENT UNIT HOURS STATE AVE	%	WORK UNIT PER EQUIP UNIT YEAR	WORK UNIT PER EQUIP UNIT STATE AVE
121	MIXING BIT	YDS	936	1956	170	1	435	2	5.5	4.5	1984	1	7769	2	0.4	0.2
122	SURF PATCH BIT	YDS	6002	2225	4337	8	1869	5	1.3	1.1	16228	4	8995	3	0.3	0.2

DISTRIBUTION MAINTENANCE HEADQUARTERS
DIVISION
DISTRICT

WORK ACCOMPLISHMENT REPORT
FOR YEAR ENDING JULY 31, 1969
SUB-DISTRICT NO. 4-2-2

(EXAMPLE)
1970 FISCAL YEAR TO DATE

WORK CODE	DESC.	UNIT	WORK UNITS YEAR ACC	WORK UNITS DIST AVE	MAN HOURS YEAR ACC	%	MAN HOURS DIST AVE	%	WORK UNIT PER MAN HOUR YEAR	WORK UNIT PER MAN HOUR DIST AVE	EQUIPMENT UNIT HOURS YEAR ACC	%	EQUIPMENT UNIT HOURS DIST AVE	%	WORK UNIT PER EQUIP UNIT YEAR	WORK UNIT PER EQUIP UNIT DIST AVE
121	MIXING BIT	YDS	708	236	140	2	47	1	5.0	5.0	1968	4	656	2	0.3	0.3
122	SURF PATCH BIT	YDS	718	390	907	14	577	12	0.7	0.6	3732	8	2337	7	0.1	0.1

Figure 2. Monthly work accomplishment report.

unit hours have remained fixed while the dollar value of contractual work has also re mained fixed.

SUMMARY

Because Kansas is located near the center of the nation and is the crossroad for many tourists throughout the summer months, it is imperative that all surface maintenance be completed at an absolute minimum of inconvenience to the traveling public. This was the motivating factor for repairing all major surfaces with a one-pass operation and with a material that allowed the edge and centerline pavement markings to be placed on the same day. For that reason, management was receptive to all the changes necessary to establish a positive maintenance program, to staff and equip the subdistricts, to maintain quantity-quality controls, and to balance the workload between state and contract forces.

A Detection System for Frost, Snow, and Ice on Bridges and Highways

MICHAEL F. CIEMOCHOWSKI, Holley Carburetor Company, Warren, Michigan

The twofold problem of detecting frost, ice, and snow conditions on the deck areas of highway bridges and overpasses, and providing suitable warnings to motorists has become an increasingly important and critical highway safety problem on high-speed Interstate highways. The author describes a system developed by Holley Carburetor Co. that detects these conditions through the use of a combination ambient air and relative humidity sensor on the bridge railing along with two other sensors buried in the bridge deck. The results of a 3½-year evaluation program of the system that actuates a flashing sign on the Flint River bridge on I-75 near Flint, Michigan, are described.

The paper also introduces a new dual-channel detection system for frost, ice, and snow. This system splits the anticipatory frost and the snow and ice signals into two separate signals. The anticipatory signal can be relayed as an early warning to alert maintenance staffs to send an observer to examine the conditions firsthand and pass a judgment on the need for chemical application or sign actuation. The early warning signal can also be used to switch-on electric heaters embedded in the deck. The separate ice and snow signal can be used to actuate a warning flasher. Also mentioned are two new applications of the dual-channel system on highways as the first application of a similar system on an airport runway.

•THE FORMATION of frost, snow, and ice on the road surfaces of highway overpasses and bridges presents a real driver safety problem. This is caused mainly by initial freezing that occurs only on surface not in contact with the ground. As a result, the motorist is totally unprepared for the slippery pavement areas and is usually traveling too fast to cope with them. The pileups on bridges and overpasses that occur when a single motorist loses control of his car are monumental and a matter of record.

In 1964, engineers at Holley Carburetor Co. developed an anticipatory system for detecting the formation of ice on the inlet surfaces of stationary gas turbines. This system prevented ice formation by directing hot air to the inlet surfaces of the turbine only when ice conditions were present. Because the direction of hot air to the inlet surfaces cuts turbine efficiency by up to 15 percent, the system served the dual purpose of preventing ice formation and keeping turbine operating efficiency high. These patented systems use an ambient temperature sensor and a unique relative humidity sensor to monitor the ice-forming conditions. More than 100 Holley gas turbine, ice-detection systems are operating successfully today.

THE HIGHWAY ICE-DETECTION SYSTEM

Success with the gas turbine, ice-detection system led Holley engineers to develop an anticipatory system of a similar type that could be applied to detect frost, snow, and ice conditions on highways. This system (Fig. 1) consists of a humidity and ambient temperature sensor that is mounted on the side of the bridge railing near the deck.

Paper sponsored by Committee on Snow and Ice Control and presented at the 48th Annual Meeting.

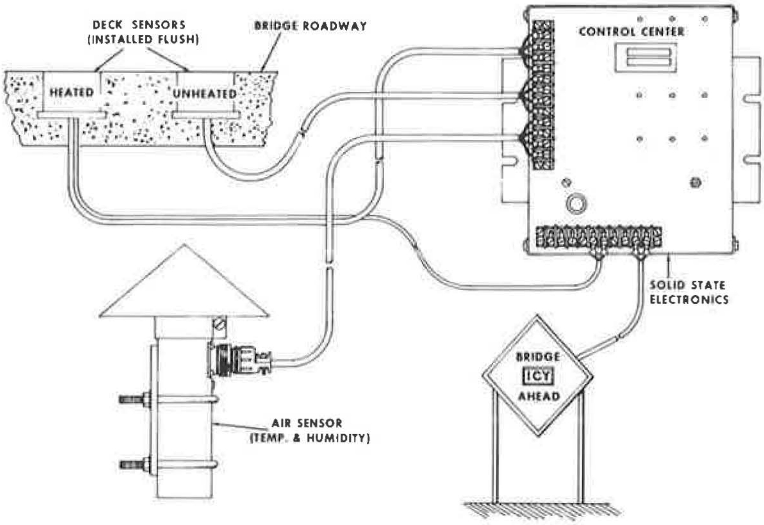


Figure 1. Schematic diagram of the ice-detection system.

Two deck sensors are embedded in the bridge deck flush with the surface. Sensor connecting cables are strung in conduit and connected to a control center mounted near a power supply below the bridge. Output terminals from the control center are connected to lines leading to electric warning signs that flash a BRIDGE ICY signal to the motorist.

The all-solid-state, weatherproof control center includes an amplifier, freezing temperature reference, relative humidity reference, comparators, and a relay that closes to operate the warning sign. The system operates from an 85- to 130-volt, 60-hertz, single-phase electric power source. It has a continuous 1.5-watt power absorption and a momentary absorption of 30 watts. It operates in a range of -55 to +160 F. The temperature and humidity settings are adjustable. The temperature readout is from -40 to +130 F. Humidity readout is from 60 to 100 percent relative humidity. The relative humidity sensor has a humidity-sensitive film deposited on a conductive grid.

HOW THE SYSTEM WORKS

The system has both anticipatory and ice-formation modes. If the bridge deck temperature equals the saturation temperature of the air, condensation of water vapor will occur on the deck surface. When the temperature falls below the saturation temperature, condensation is accelerated. If the deck temperature is at or below 32 F, ice will form. The saturation temperature (the equivalent of 85 percent relative humidity) is calculated to be 3.1 F below the ambient temperature.

By comparing the differential temperature between the ambient and deck surface, the system predicts when frost will appear on the deck. Setting the electronic logic to take action when the relative humidity to saturation differential is slightly larger than the deck to ambient temperature differential enables frost to be anticipated before it forms. Three input signals are combined to activate the anticipatory portion of the system: (a) a bridge deck temperature of 32 F or below, (b) a bridge deck temperature at least 3.5 F below ambient air temperature, and (c) a high relative humidity.

Precipitation can also occur on a bridge deck when humidity is low, and ice could form if the deck is at freezing temperature. This condition would not be detected by the anticipatory system, but is monitored by two sensors flush-mounted in the deck. One sensor has a thermistor-regulated heating element to maintain its temperature at 38 F or higher. The other sensor is unheated and measures deck surface temperature. These sensors function because of the conductive phenomenon between ice and water.

Figure 2. Electric flasher that warns of icy conditions on highway overpasses and bridges.

Figure 3. Location for the temperature- and humidity-sensor unit on a bridge railing.

Water has a high conductance whereas ice has a low one. To sense this difference, ach sensor has two sets of cylindrical electrodes with a gap between each electrode.

When freezing rain or snow occurs, and ice builds up on the deck surface, the unheated sensor has ice between its electrodes, providing low conductance. The heated sensor has water between its electrodes and signals a high conductance. Thus, a conductive imbalance occurs between the two sensors and an icing signal is generated. When salt or other freezing-temperature reduction media are applied for de-icing of the deck surface, the ice on the unheated sensor melts, conductive balance is restored, and the icing energizing signal is removed. The ice-formation signal requires two input signals to be initiated: (a) a bridge deck temperature of 32 F or below, and (b) a conductive imbalance between the deck sensors.

Figure 4. Installations of the ice-sensor units in the bridge deck surfaces.

THE INITIAL SYSTEM EVALUATION PROGRAM

In 1964, the first Holley ice-detection system was installed on the Flint River bridge on I-75 near Flint, Michigan. This system (Figs. 2, 3, 4, and 5) actuated a warning sign. It included a set of recorders that kept a record of ambient temperatures and relative humidity readings as monitored by the detection system, as well as a record of sign actuation.

Figure 5. Location of the power supply and control center on the Flint River bridge application on I-75.

Figure 6. Control center and sensor units for the new dual-channel detection system for frost, snow, and ice on highway overpasses and bridges.

In this 3½-year evaluation program, the recorded temperature and humidity readings were correlated with those of the U.S. Weather Bureau recorded at the nearby Bishop Airport in Flint, Michigan. The reliability of the system's records of temperature and humidity and of its sign activation was excellent. Accuracy of temperature readout for the system is now specified at ± 1 F. Relative humidity readout accuracy is ± 2 percent.

Many highway officials have found over the years that accidents cannot be prevented by signs alone, no matter how they are designed, built, installed, or operated. In the case of slippery highways, the correct solution is probably to examine the condition and to get rid of the frost, ice, or snow. As a result of these recent safety interpretations by highway officials, a new dual-channel system has been developed (Fig. 6).

THE NEW DUAL-CHANNEL SYSTEM

The new dual-channel system for frost, snow, and ice detection has the capability of splitting the warning signal to differentiate between a frost condition and an ice or snow condition. One signal is generated by the anticipatory portion of the system. The other signal is generated by the snow and ice-formation portion.

The anticipatory signal provides an early warning that can be relayed by radio or other communication means to maintenance personnel who can send an observer to the area to study the condition firsthand. The observer can then judge whether or not to call a crew to apply de-icing chemicals. Provision can also be made, if desired, for the observer to manually actuate a warning flasher. The early-warning signal can also be used to switch on electric heating elements embedded in the deck. The second signal is generated by the presence of ice or snow on the bridge deck and generally actuates a flasher sign to warn motorists of the hazardous driving condition.

The block diagram for the new dual-channel system is shown in Figure 7. All-solid-state components provide system reliability. Two relays provide the individual anticipatory and ice-formation signals.

NEW APPLICATIONS OF THE SYSTEM

The highway departments of both California and Illinois are now installing this new dual-channel, ice-detection system. The Illinois installation is on the Blodgett Bridge on I-55. Airport runways are another application where early detection of frost is needed along with ice and snow detection to provide maximum passenger safety. Airports plan to solve the problem by applying anti-icing chemicals when ice conditions are anticipated. A dual-channel system has now been installed on one of the runways of one of the world's largest airports. It is now undergoing complete evaluation tests, which will be reported at the end of the winter of 1968-1969.

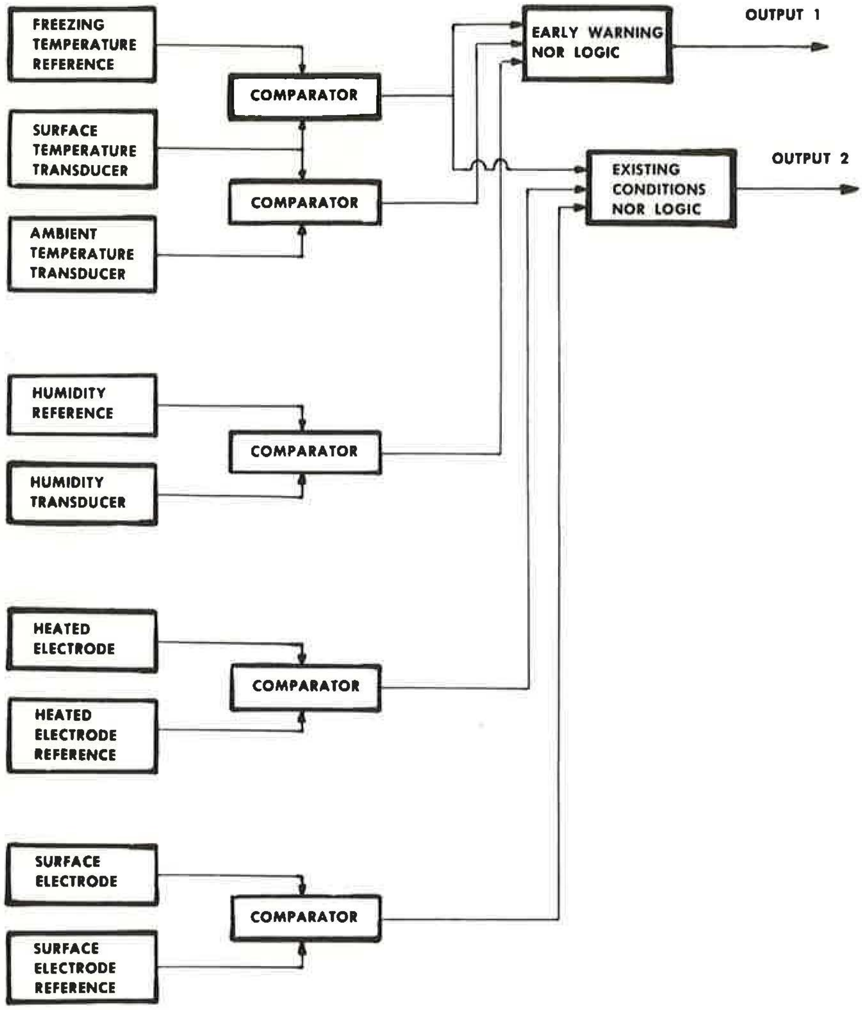


Figure 7. Block diagram for the anticipatory dual-channel, ice-detection system.

Discussion

FOSTER A. SMILEY, Iowa State Highway Commission—Technical progress in both equipment development and highway construction has improved highways to such an extent that travelers expect normal driving conditions on highways in the winter, summer, spring, and fall regardless of the elements of nature. We have gone from slow, antiquated snow removal units to new, high-powered trucks with related snowplow equipment that can quickly and efficiently remove snow and ice from the traveled portion of the highway system.

Regardless of the improvements in equipment and highways, highway maintenance engineers are still faced with one of the same problems that have been with us since the around-the-clock policy for snow and ice removal was established. We still need a reliable method to use so that local maintenance foremen can be advised when the roads are becoming icy and require attention, particularly during the night.

Because bridge surfaces are more susceptible to frost than are pavement surfaces, we developed several rules of thumb to predict the conditions that develop on bridge surfaces in winter weather; but these were not as sophisticated or as reliable as we needed.

Nor did the electronic ice-detecting units that were developed and used to activate lights on signs to warn motorists of ice on bridges seem to be very desirable or practicable because there are over 3,000 bridges on the primary road system in Iowa. It seemed more reasonable to have a system that would warn of an icing condition so that general corrective measures could be taken. In 1964, we decided to use our mobile radio system in some manner to broadcast a message when frost or ice was present. A review of available electronic ice-detecting units indicated that they could be used to trigger a radio transmitter. Although these units were found to be unreliable at times and occasionally became inoperative, they gave us a starting point from which to develop greater reliability and to learn about requirements for maintaining ice-detecting units.

Our first ice detector, an "Econolite" purchased from a Los Angeles company, is installed in a bridge floor on US-30 in Crawford County. The output from this detector is transmitted through a radio transmitter mounted on a utility pole adjacent to the bridge to a mobile relay transmitter of our two-way radio system. The relay repeats the signal so that it is received in the maintenance foreman's home on a special receiver that is activated only by a predetermined signal. The signal is also received by the maintenance mobile unit. The transmitted signal could activate any number of devices such as one that would ring a bell or even turn a bed over. We have taken a more gentle approach and have chosen to broadcast a three-pulse tone once a minute for five minutes of each hour when a slippery condition exists.

In 1965, the department purchased two "Icelert" detector units from Findley-Irvine, Ltd., of Scotland. These units are very reliable in reporting frost, but had to be modified to report packed snow and also to eliminate the signal if a nonslippery salt-brine condition existed. One of these units is in a bridge at the junction of US-30 and US-69 near the south edge of Ames and the other is in a bridge on Iowa-163 at the east edge of Des Moines. After experimenting with and remodeling these units during the winters of 1964, 1965, and 1966, we felt that a reliability of about 80 percent had been achieved. Although this reliability was reasonably good, we felt it must be in the 95 to 100 percent range before it would be acceptable. It is our opinion that when you get a maintenance foreman out of bed at three in the morning, it had better be for a very good reason. We, therefore, began a research project in 1967 to develop a more reliable frost- and ice-detection system for highway bridges. Work on this project is under way and some general conclusions can be made.

In 1967, the department requested information from another state highway department on its experience with the system for frost, snow, and ice detection on bridges and highways, which was developed by the Holley Carburetor Co. and was being used experimentally by that highway department. We reviewed the information furnished and concluded that, although highly sophisticated compared with the Icelert or Econolite detectors, the Holley unit still left something to be desired. Based on the information we have gathered, we would like to comment on the Holley detection system as follows.

The Holley detector device has two noteworthy features. The first feature allows it to predict freezing conditions. The second feature allows it to detect ice and snow directly. Both features perform independently of each other and have separate outputs for signaling purposes.

The prediction of frost conditions is based on the evaluation of ambient temperature, humidity, and deck temperature. An assumption is made that water freezes at 32 F. This would be true if salts (calcium chloride and sodium chloride) were not present on the pavement deck surface. Under these circumstances the predictions would be accurate. In the presence of a significant amount of salts (sodium chloride or calcium chloride), an indeterminate prediction results. Figure 8 shows the freezing point as it is lowered by various concentrations of sodium chloride, NaCl, and calcium chloride, $CaCl_2 \cdot 6H_2O$. In Iowa we have found heavy frost on bridge railings at a temperature of 15 F when there was no frost on the bridge deck itself. This difference was due to the addition of calcium chloride to the bridge surface within the week immediately preceding the observation. Once calcium chloride is on a bridge deck, it is very difficult for frost to form. A high humidity and a very sudden temperature drop, approximately to the 10 to 15 F range, are required for the formation of frost, and under these

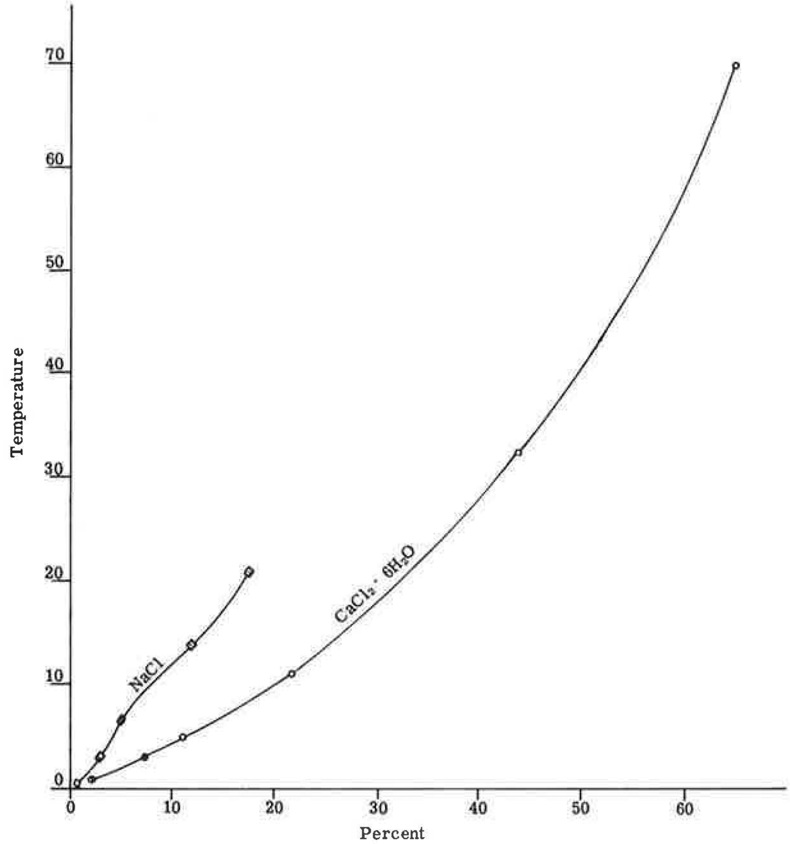


Figure 8. Percentage of salt solids (NaCl and $CaCl_2$) by weight vs degrees of temperature lowering F.

conditions all the theory about radiation of heat from a bridge deck can be forgotten. Based on the description of the operation of the Holley detector, we agree that it would work ideally for the first frost detection of the season. If sodium chloride or calcium chloride were added to remove this frost, however, the succeeding readings could be inaccurate or of questionable value.

The second feature of the Holley detector, the reading of ice and snow directly, is based on the same principle as that used by the Econolite and Icelert detectors. One heated and one unheated transducer embedded in the pavement are compared for conductivity. If water is deposited on both transducers, the conductivity is the same and the output is balanced. If frozen water is deposited on the transducers, the heated transducer will conduct and the unheated transducer will not conduct. An unbalanced output indicates ice. This detection method would be reliable as long as the moisture has a very low salt content, such as that in tap water. However, when the salt content is increased, there is no difference in the conductivity of the frozen water and unfrozen water. After the first frost of the season, the salt content of moisture on the bridge deck becomes unpredictable, and so does the reliability of any output signal that uses conductivity transducers to indicate the presence of moisture, frost, or ice when salts (calcium chloride and sodium chloride) have been applied on a bridge deck.

Regarding the Holley Carburetor Co.'s 3½-year evaluation program, Ciemochowski, states: "Excellent reliability was recorded for the system in temperature and humidity recording as well as sign activation." We are of the opinion that reliability of a frost- and ice-detector system should be related not to the elements of the system, but to the complete operativeness or output of the system—i.e., we would express the percentage of reliability to be in accord with the following formula:

$$\text{Reliability Percentage} = 100 - \frac{\text{(number of detector errors)}}{\text{(number of slippery conditions)}} \times 100$$

Because of the basic deficiencies of all the commercially available ice detectors on the market today, including Econolite, Icelert, and the Holley detector, the research work done by the Iowa State Highway Commission has concentrated on an approach to the detection of slippery bridge deck conditions different from that which uses the transducers and conductivity cells or both. We are pleased to report that at this time a prototype detector, which is a product if this research work, is installed on a bridge at the junction of US-69 and US-30 near Ames. We feel that, with the experience gained in the 1968-1969 winter season, we will be able to debug our ice-detection system and in another year be able to present information on a detector system that will actually have 95 percent or greater reliability.

MICHAEL F. CIEMOCHOWSKI, Closure—In reviewing the discussion of my paper, I am compelled to clarify some points regarding the operation of the Holley system. These points are as follows:

1. With reference to the discussion regarding two competitive units, I would note that (a) these units have two embedded sensors with a relatively large gap causing sensitivity to be very limited; and (b) because one electrode is heated, it is always above dew point causing the detector to be incapable of detecting frost and to be limited to detecting existing snow.
2. The Holley early warning system monitors humidity, surface temperature, and ambient temperature, and determines the difference between surface temperature and ambient temperature. Humidity may be expressed in terms of differentials of dew point and ambient temperature. Thus, if the humidity differential equals the ambient-surface differential, below 32 F, it means that surface is at dew point and frost will form.
3. A unique feature of the Holley system is the fact that the deck transducers have a very narrow gap. This permits extremely high sensitivity. This gap also possesses capacitance as well as resistive qualities. In the paper, I referred to conductance changes alone for simplicity. However, the detection network is much more complicated. In reality, the change in AC impedance is measured on both electrodes. As a result, the presence of sodium chloride or calcium chloride is detected by these sensors. If an early warning is generated and the presence of de-icing agents is detected, the alert is aborted. For this reason, high resolution differential amplifiers and operational amplifiers are used and not bridge circuitry.
4. The Holley unit, to date, has been based 100 percent on the formula given in the discussion. The early warning, of course, is adjustable and anticipation required, say one hour ahead of actual formation compared to 15 minutes, may materialize or it may not. Thus, long anticipations for accurate alerts are not recommended. In the 15-minute anticipation area, the system is and has been 100 percent correct for the past two years. This is based on actual observations.

I may add that this system has similar performance records in New York, Illinois, California, and Michigan. This year the system has been modified, improving its performance and reliability.

Use of Salt for Winter Maintenance of Roads in Great Britain

E. K. WILLING-DENTON, Imperial Chemical Industries, Ltd., England

This paper gives an account of developments in the use of salt without grit admixture for winter road treatment in Great Britain. Consumption of salt has risen tenfold in the past 12 years. Anticaking treatment of rock salt made large-scale prewinter stocking of salt a practical proposition since 1956. Most stocks are held as outdoor heaps without protection from rain, but there is a growing interest in covering such stockpiles with plastic sheeting.

The preferred grade of road salt contains both fine and coarse particles, and modern spreading equipment has been designed for such a grade. The rates of application generally used are ½ oz per square yard for precautionary spreading before frost or snowfall, 2 oz on thin ice films, and 2 oz per square yard, repeated as necessary, for snow treatment. In rural areas, plowing to prevent accumulations caused by drifting is normal when snow is about 2 in. deep. On some main roads, considerably greater falls of snow than this are dealt with by the combined effects of salt and traffic.

BRITISH CHILDREN have long been taught that their islands have a temperate climate because of the influence of the warm Gulf Stream and prevailing mild, wet, westerly winds from the Atlantic Ocean. True, there are a few well-sheltered spots in the west of the British Isles, including even the northwest coast of Scotland where palm trees and other semitropical plants have been induced to survive, but the belief that Britain has generally mild winters has, until very recent times, affected popular attitudes toward dealing with problems caused by winter weather. For example, the traditional British attitude toward domestic central heating was that it was not only unnecessary, but was also an unhealthy and faintly sinful self-indulgence. The truth is that in some winters practically the whole of Britain can have snowfalls and freezing temperatures when north or east winds blow for several days—or even weeks—at a time. Many areas of the country experience sharp frosts and snowfalls every winter, although they vary in duration and intensity from year to year. In an average British winter, we expect that from December to March most of the country will be subject to frequent icing conditions, especially at night, and that there will be about 12 days when the ground is covered in snow. About once in every 7 years we get a winter of unusual severity, and the average Briton adopts an attitude of surprise and disapproval.

This attitude had a strong influence on the approach to winter road maintenance. Until the middle 1950's, only very limited use was made of salt for winter road maintenance in Britain. The amount of salt held in stock in advance of winter by highway authorities was negligible.

DEVELOPMENT

In the 1950's, there began a rapid expansion in the number of commercial and private motor vehicles on British roads. In 1955, there were 6½ million vehicles in the country and 188,000 miles of highways. Today, there are 13 million vehicles and 201,000 miles

Paper sponsored by Committee on Snow and Ice Control and presented at the 48th Annual Meeting.

of highways. This increase in traffic was accompanied by an increased public demand and economic need for a higher standard of winter road maintenance. The last 10 years or so has seen a very rapid increase in the use of salt for winter road treatment. In the 1940's and early 1950's, the consumption of salt for winter road maintenance in Great Britain ranged between 20,000 and 75,000 tons a year. The demand rose to half a million tons in 1962, and in 1968 it will be 1.3 million tons. In recent years, 60 percent of this salt has been taken by county authorities and 40 percent by urban authorities.

Of the 201,000 road-miles in Great Britain, about a third are regularly treated with salt in winter. The central government pays the entire cost of winter road treatment on all motorways and trunk roads, and also contributes to the costs incurred by county and urban authorities in treating other roads.

Two practical problems had to be overcome before salt could make its contribution to achieving a higher standard of winter road maintenance. First, salt in suitable condition for spreading had to be made available where and when it was needed. Second, the traditional practice of spreading the salt by manpower and shovel had to be replaced by rapid mechanical spreading of the salt in quantities appropriate to the conditions.

The basic technical solution to the first problem became available with the introduction of anticaking treatment by potassium ferrocyanide. In 1956, this treatment was applied to a grade of rock salt, developed by the Imperial Chemical Industries (ICI) for winter road treatment, that contained a balanced mixture of fine and coarse particles. This provided a salt that would not set hard, and that could be stored by local authorities for long periods with the confidence that, when needed, it would be in suitable condition for spreading effectively. The solution to the second problem called for the development and manufacture of motorized machines refined in design to spread salt evenly at rates between ½ and 4 oz per square yard, as required. These rates are equivalent to 365 lb and 2,950 lb per mile when spreading to a width of 20 ft.

In 1953, the British Road Research Laboratory published a report in which it summarized existing knowledge and experience of winter road treatment with salt (1). In 1954, highway authorities were made aware of the need to stock greater quantities of salt and the desirability of using salt by itself, free of sand or grit. There are very real advantages to be gained by using salt alone. Salt melts ice and snow, and clears the road surface; grit only provides an improvement in grip on icy surfaces, and even this effect is temporary because the grit is thrown off by traffic. Because a lower density of spreading is required for salt than that for salt with mixtures, a greater number of road-miles can be treated in a given time, and more efficient use is made of the spreaders' running time. Prompt treatment with salt alone results in a reduction of the amount of treatment necessary, and also a corresponding reduction in costs. Substantial savings are also made by eliminating the cost of grit, the cost of mixing, and the cost of removing grit from channels and drains.

From the early experience of those counties that tried using salt alone on a large scale, it was clear that salt spread lightly in advance of frost would not only prevent the formation of ice, but would also remain effective for up to 2 days under normal conditions. Salt spread somewhat more heavily before or during a moderate snowfall would prevent the snow from sticking to the road and would convert it to slush, which would in turn be dispersed by traffic.

This experience was especially valuable in a study of snow and ice removal that was made by the Ministry of Transport shortly before the opening of the first British motorways in 1958 and 1959. County authorities were to be responsible to the Ministry for maintaining sections of motorways within their boundaries, and they agreed to the following policy for winter maintenance of motorways:

1. Carriageways should be kept free from frost at all times.
2. Under the worst snow conditions, at least one lane of each carriageway should be kept open for traffic.
3. The basis of treatment to achieve these requirements is the use of ground rock salt without an admixture of grit.

To implement this policy, the Ministry cooperated with equipment manufacturers in improving the design of salt-spreading vehicles, and it established depots or maintenance compounds on the motorways at about 12-mile intervals to provide supplies of s rapid means of loading the vehicles, standby quarters for winter maintenance crews, and facilities for servicing and refueling the vehicles. These depots are built on sites of about 2 acres and have direct access to the motorway. Provision is made for the open-air storage of about 2,000 tons of salt at each depot, and usually there are twin 50-ton loading hoppers. Normally there is a 75-ft square garage area, together with messroom for up to 12 men, a bunk room with 4 beds for emergency use, several stores, and offices. Fuel and fuel pumps with 1,000-gallon tanks are provided. These depots are operated by the county councils, as agents for the Ministry of Transport. The county and urban authorities also have their own depots, on the appropriate scale, from which they carry out winter maintenance on their own roads.

STORAGE OF ROCK SALT

Prior to 1956, a serious obstacle to the use of salt for winter road maintenance was the difficulty of ensuring that the salt was available when required, because the caking problem did not allow stocks to be built up. With the introduction of anticaking treatment in 1956, the large-scale storage of rock salt became practicable. A trial showed that an outdoor heap of about 5,000 tons of treated rock salt did not cake but remained in a suitable condition for spreading even when the salt was not covered. This development was publicized in 1958, and since then the highway authorities have laid down prewinter stocks in ever-increasing quantities. By 1962, the highway authorities were holding prewinter stocks amounting to a quarter of a million tons throughout the country, and now such stocks amount to about one million tons. The highway authorities were given a rebate of about 7 percent to encourage the depots to take deliveries during the summer months, i.e., April to September.

The bulk of the rock salt is still stored without any protection from the weather, but there is now a growing interest in covering the heaps with waterproof sheets for two reasons. First, covering will prevent the so-called "freezing" of salt (actually a type of caking attributable to the crystallization of sodium chloride di-hydrate), which can occur if wet salt is subjected to very low temperatures for a long period of time. Second, it will prevent losses caused by rainfall. Such losses depend on the size and shape of the stockpile, the type of ground on which it is stacked, and the amount of rainfall.

Recent work by the Road Research Laboratory (2) has led to the conclusion that, from large stockpiles of typical shape, the loss per year is about ⅛ percent of the initial weight of the pile for each inch of annual rainfall. Because the amount of salt dissolved from a heap is limited by the amount of rainfall and by the solubility of salt in water, the actual loss from any stockpile will depend only on its area. An obvious way of reducing the loss is thus to stack the salt to the maximum height possible.

At the rock salt mine in Winsford, Cheshire, the rock salt is stacked 20 to 25 ft high, but the more usual height of a stockpile at highway authority depots is about 12 ft. This is probably as high as it is safe and practicable to go, because of the risk of falls when recovering salt from the pile.

SPECIFICATION FOR WINTER MAINTENANCE SALT

In 1960, the general increase in the use of salt for winter highway maintenance, which had by then taken place, led the British Standards Institution to undertake the preparation of a specification for this product. The grade of noncaking rock salt developed by ICI—having been successfully used for about 5 years and amounting at that time to about 90 percent of the winter maintenance salt used—naturally formed the basis of the draft specification.

After trials and investigations, in which representatives of all the government departments and scientific and industrial organizations concerned took part, the Institute issued British Standard 3247, Part 1, that is given in Appendix A. The standard includes tests for certain of these properties and specifies the essential properties of a rock salt for winter maintenance. The main requirements of British Standard 3247, Part 1, refer to storing quality, grading, and chemical composition.

Three years later, British Standard 3247, Part 2 (Appendix B), was issued, covering salt other than rock salt. This specification is the same as British Standard 3247, Part 1 in the storing quality and chemical composition requirements, but specifies different gradings. Less than 5 percent of the total tonnage of salt used for winter maintenance is other than rock salt.

SALT SPREADING EQUIPMENT

There is also a British Standard specification for salt or grit spreading vehicles (British Standard 1622, 1960). This specification was originally issued in 1950, when gritting techniques were relatively undeveloped and salt was used mainly in combination with grit, sand, or ashes. A revision of this specification was necessary by 1960 because British manufacturers had developed more sophisticated spreading machines to match changing techniques in winter road maintenance. The important changes in technique were based on the use of salt alone, not only for the removal of snow and ice, but also for precautionary treatment in advance of such conditions. The economic use of salt called for gritters able to spread as little as 1 oz per square yard uniformly over wide carriageways at relatively high speeds between widely separated stockpiles. The machines also had to be able to operate with equal effectiveness at rates up to 4 oz per square yard for the treatment of snow. The revised specification divided winter spreaders into three classes, primarily based on spreading characteristics and speed of operation, and it included details of construction, performance, and testing for each class. The types of salt-spreading equipment most commonly used for winter road maintenance in Great Britain are described briefly in Appendix C.

PRESENT WINTER MAINTENANCE PRACTICE

Road Note 18 of the Road Research Laboratory, referred to previously (1), was revised in 1968 to take into account the developments in the salt treatment of snow and ice on roads that had taken place during the 15 years since it was issued. Recommendations for the use of salt are given, based on methods that have been found to be successful and economical.

Although the temperature at which any quantity of salt would fail to melt ice is -21 (-6 F), in practice salt is not often used in Great Britain at temperatures below -10 C (14 F). In fact, according to the Road Research Laboratory findings, most icing conditions and snowstorms experienced in Great Britain occur at temperatures above -3 C (27 F).

In the early days of the use of salt without grit admixture, attempts were made to estimate the severity of the conditions and to adjust the rate of application accordingly. Nowadays, because salt is applied at the earliest possible moment, and before the occurrence of frost or snow whenever possible, the practice is to apply salt at a standard rate sufficient for average conditions, and to repeat the application to the extent that it is necessary. These standard amounts are lower than the quantities formerly used, and this has the advantage of increasing the distance covered by each spreader-load of salt. The greater the mileage covered in the early stages, the better because the effect of traffic is to break down the snow once it has been salted; whereas on snow that has not been salted, the effect of traffic is to pack the snow into ice.

The highway authorities make use of a service provided by the Meteorological Office for a small annual fee, and obtain warnings of expected icy conditions or snowfalls. These warnings are provided from local meteorological stations. The forecasts are not invariably correct, but the view is generally held that, although salt may be wasted occasionally on unnecessary operations, this is much outweighed by the savings made by prompt spreading where snow or ice actually occurs. In addition to these forecasts, several highway authorities have installed detector systems. These signal to a highway depot or to a foreman's home when icing conditions are likely to occur at the sites where the detectors are installed. They operate by measurement of humidity and temperature, and the more recent models also measure the presence of salt on the road, canceling the warning if there is salt remaining that will prevent ice film formation.

For precautionary spreading, a rate of application as low as ½ oz per square yard (365 lb per mile) is sometimes used. Some engineers prefer to use higher minimum rates to ensure that no blockage of the spreaders occurs. On some machines, when preading on narrow roads, only a very narrow opening of the feed-gate is required at the lowest rate of application. Should a blockage occur, this could remain undetected when salting at night, and a dangerous situation would arise if a length of road were left unsalted.

Thin ice films on the road surface are usually less than 0.01 in. thick, and this amounts to about ½ lb of ice per square yard. Because the temperature is usually above -3 C (27 F), only ½ oz of salt per square yard (365 lb per mile) is needed to melt this weight of ice completely. Therefore, only ½ oz of salt per square yard is used for precautionary spreading to prevent the formation of these thin films of ice, or to prevent snow from adhering to road surfaces. If, however, ice has already formed, salt is used at the rate of about 2 oz per square yard (1,475 lb per mile) to ensure that the ice is speedily removed.

A normal density of fresh snow is about 6 lb per cubic foot, so that a 1-in. depth of snow weighs about 4½ lb per square yard. It has been found in practice that half the quantity of salt required for complete melting will reduce the snow to a slush that is dispersed by traffic, and, to get this condition, about ½ oz of salt per square yard (365 lb per mile) is required per in. of fresh snow per degree Centigrade that the air temperature is below freezing point. One or two applications of salt at 2 oz per square yard (1,475 lb per mile) are found to clear the average snowfall.

If snowfall continues, the salting is repeated, and snowfalls of as much as 10 in. have been cleared in urban areas solely by the use of salt. It is more usual, however, to commence plowing when the depth of snow reaches 2 in. or so, and to spread salt at the rate of 1½ to 2 oz per square yard (1,100 to 1,475 lb per mile) after each passage of the plow. The salt prevents snow layers from bonding to the surfaces of the roads, thus making plowing easier and preventing the formation of packed snow layers.

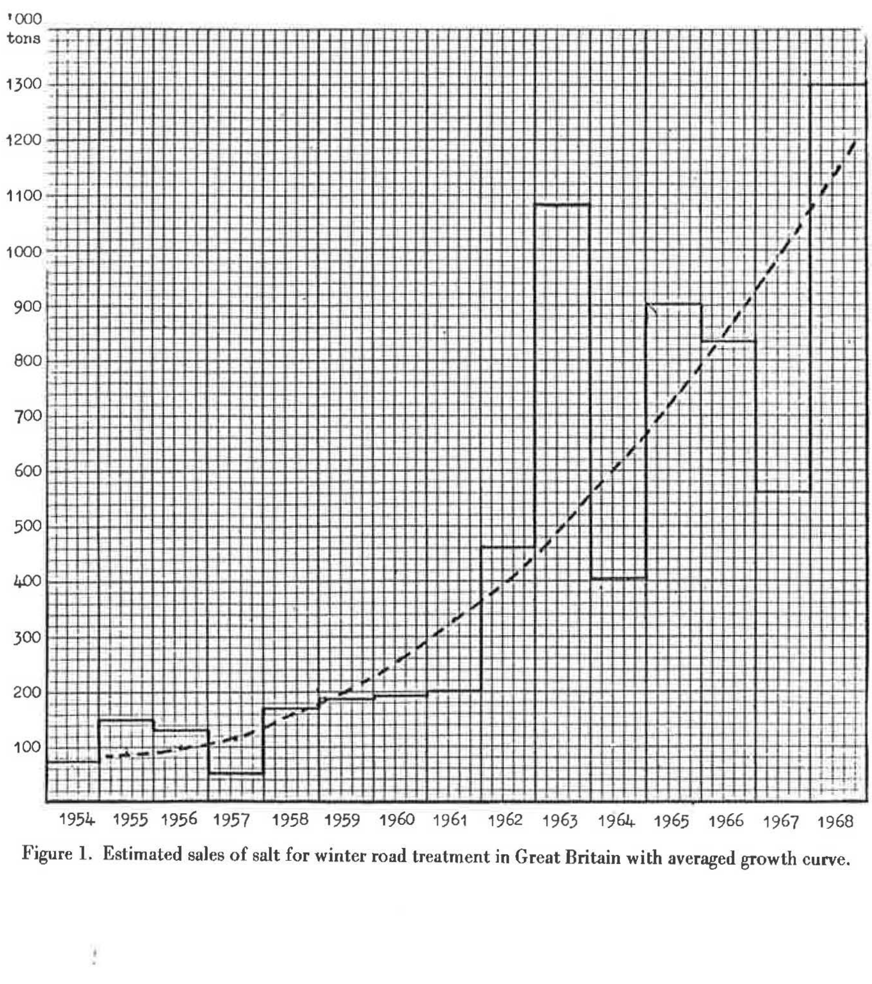


Figure 1. Estimated sales of salt for winter road treatment in Great Britain with averaged growth curve.

If hard-packed snow layers have been allowed to form, they are often removed by the use of very heavy applications of salt, assisted by the traffic. Alternatively, abrasives such as grit, ashes, or sand may be used to provide adhesion for vehicle wheels. These materials are also sometimes used on steep gradients, but present practice in Great Britain is to keep their use down to the minimum.

GROWTH IN THE USE OF SALT FOR WINTER ROAD TREATMENT

The estimated annual sales of salt for winter road treatment in Great Britain over the last 15 years are shown in Figure 1. Currently, the use of salt on Britain's roads in an average winter appears to be increasing at about 150,000 tons a year, based on a relatively simple analysis of meteorological records, but attempts are being made to verify this by a more detailed statistical analysis. An investigation is also being made to try to forecast how the rate of growth in demand might change in the future, and what the consumption of salt for roads might be for an average winter in 10 to 15 years. Solution of the latter problems depends on many factors, including questions of how closely all highway authorities are already approaching optimum use of salt in existing conditions, how much these conditions will change as new roads are developed, and how soon treatment will be extended to minor roads that carry little traffic at present but that might have to carry increasing volumes to feed main routes in the future.

REFERENCES

1. Salt Treatment of Snow and Ice on Roads. Road Research Laboratory, Crowthorne, Berkshire, England, Road Note 18, 1968.
2. L. E. Hogbin. Loss of Salt Due to Rainfall on Stockpiles Used for Winter Road Maintenance. Road Research Laboratory, Harmondsworth, England, Rept. 30, 1966.

Appendix A

BRITISH STANDARD 3247—1960

SPECIFICATION FOR SALT FOR SPREADING ON HIGHWAYS FOR WINTER MAINTENANCE PART 1. ROCK SALT

The main requirements are as follows:

Chemical Composition (calculated on a moisture-free basis)

Sodium chloride, NaCl (including $MgCl_2$ and $CaCl_2$ expressed as sodium chloride)	not less than 92 percent
Soluble sulphate compounds expressed as $CaSO_4$	not more than 1.5 percent
Material insoluble in water	not more than 6 percent

Grading

British Standard Sieve	Percentage Passing
$^3/_8$ in.	100
No. 7	30 to 70
No. 52	0 to 20

Storing Quality

The bulk of the salt shall be in a loose and usable condition after open storage for 18 months in an unprotected stockpile at least 4 ft high with sides inclined at the angle of repose of the salt.

Under these conditions any nonfriable crust formed shall not exceed 3 in. in thickness.

Appendix B

BRITISH STANDARD SPECIFICATION 3247—1963

SPECIFICATION FOR
SALT FOR SPREADING ON HIGHWAYS FOR WINTER MAINTENANCE
PART 2. SALT OTHER THAN ROCK SALT

The requirements are the same as those for rock salt in Standard 3247, Part 1, except those for grading, which are as follows:

Salt	Passing British Standard Sieve	Percentage by Weight
Coarse	⅜ in.	100
	No. 14	80 maximum
	No. 100	0 to 10
Fine	No. 14	100
	No. 100	0 to 30

Appendix C

SALT-SPREADING EQUIPMENT IN GREAT BRITAIN

The automatic spreading vehicles most extensively used in Great Britain have a hopper body with moving floor belt delivering beneath an adjustable gate onto spinner discs. The vehicles designed for use on the motorways have a capacity of 8 cubic yards and can travel at speeds up to 50 mph. Their purpose-built chassis have 173-hp engines, driven through a 6-speed gearbox to 6 wheels. The body is made of sheet metal on a steel frame. The moving floor belt is driven from the power takeoff, and can be run in either direction, with the vehicle either moving or stationary. The salt spinners are located in front of the rear wheels, so that the salt that is being spread provides adhesion and the crew can monitor the flow of salt. The outlet gate is at the front of the hopper body, and can be adjusted to give a delivery of salt varying between ½ and 4 oz per square yard of 36-ft or 24-ft carriageway, i.e., ranging from 440 to 5,280 lb per mile. The outlet gate is divided into two parts, and either half can be closed by the driver from the cab. As one half is lowered, the other half is correspondingly raised to maintain the same total rate of salt discharge, but to either the offside or the nearside as required. The salt delivered through the gate is carried by augers, driven by power takeoff, to the offside, nearside, or both sides of the vehicle, and fed onto spinner discs. The speed of rotation of the discs must remain constant and independent of the road speed to ensure a constant width of spread. This is achieved by driving them hydraulically, directly from the vehicle engine, their speed being governed by a control valve in the driver's cab. Because the speed of the moving floor belt is directly related to the vehicle speed through the power takeoff, the rate of delivery of salt is automatically correlated to changing vehicle speeds caused by traffic or other conditions.

These vehicles, in addition to being equipped for salt-spreading, are fitted with heavy subframes and standard mountings to take large V-plows or reversible high-speed angle-blade plows. Salt-spreading vehicles of this type, although generally of rather smaller capacity and less elaborately equipped, are used by virtually all highway authorities in Great Britain.

A more recent development by the manufacturers is a demountable bulk spreader body with automatic control of spreading rate, which can be used on a flat truck or tipper lorry. The conveyor belt floor of the hopper body is driven hydraulically, the speed of the conveyor being controlled by a drive from the periphery of the vehicle's rear wheel. The single spinner is also driven hydraulically, and its speed can be set by control valve to give a width of spread from 6 to 30 ft. The hydraulic pump is driv by a built-in fuel or diesel engine. Salt can be spread to the offside, to the nearside, or symmetrically, the adjustment being made by movement of the chute feeding the spinner. These bulk spreaders usually have a salt capacity of 5 to 6½ tons. Trailer spreaders with a capacity of about 2 tons, operating on the same principles, are also used, but their popularity is waning.

In addition, there are spreading attachments that are mounted beneath the body of a vehicle, and are fed through an opening on the body floor. The salt falls through a chute and an adjustable feeder valve onto a spinner disc. The machine is driven from the rear wheel of the vehicle, to which it is attached. In this case, the width of spread is controlled by the speed of the vehicle, and is approximately 20 ft at the normal spreading speed of 8 mph.

As well as equipment utilizing spinners to spread the salt, there are also in use in Great Britain spreading machines that discharge salt directly onto the road, over their own width. A typical machine of this class is a 2-wheeled hopper trailer about 8 ft wide with a transverse slot in its base. This slot has rubber flaps with spring supports, and there is a roller (gear-driven from the trailer wheels) between the rubber flaps. For spreading salt at low rates, a roller spirally wound with wire is used to feed the salt, the rate of spreading being controlled by adjustment of the pressure on the rubber flap by hydraulic or mechanical means. There is a toothed impeller shaft mounted a few inches above and parallel to the feed roller to prevent arching, and to break up caked material. The hopper capacities range from about 1 to 3 tons of salt. These machines are designed to be drawn by tipper lorry (from which they can be refilled directly), or they may be towed by tractor.