at the onset of a snowstorm in areas where sand is undesirable. The savings to be realized from decreased plowing, sanding, and sand cleanup would influence overall costs and might significantly narrow the breakeven point between the cost of CMA and salt.

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The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation. This report does not constitute a standard, specification, or regulation.

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Staffing of Maintenance Crews During Winter Months

MARTIN C. RISSEL and DOUGLAS G. SCOTT

ABSTRACT

The Pennsylvania Department of Transportation wished to learn whether winter maintenance manpower was being used effectively and developed a research project for this purpose. The objectives of the study were to determine the cost-effectiveness of single- and dual-shift staffing during the winter months, identify maintenance activities that are not snow related and that can be performed during cold weather, estimate the amounts of work that can be accomplished with single and dual shifts, and ascertain optimum winter staffing patterns. Data from actual winters were obtained and computer models were developed to permit the calculation of regular time, premium time, and regular time when there was insufficient light to work and it was not snowing. Other states with weather similar to Pennsylvania's were contacted and furnished information about their use of maintenance manpower during the winter months. In-depth interviews were also conducted with Pennsylvania Department of Transportation personnel at various levels. A winter severity index based on total meteorological data rather than snowfall only was developed during this study to provide a means of approximating the relative severity of winters in terms of labor costs. The computer model permitted the cost-effectiveness of a wide variety of staffing patterns to be evaluated in each county in Pennsylvania. It was determined that dual-shift operation for at least part of the winter season can be more economical than single-shift operation in some districts and counties in Pennsylvania.

A major problem facing every state highway agency in the snow belt is to make winter maintenance operations as cost-effective as possible. On the one hand, safe winter driving conditions must be provided to the public and on the other, expenditures must be kept to a minimum because winter maintenance operations do not provide any lasting improvement to the highway system and can even contribute to its deterioration. The core of the problem usually concerns manpower because labor represents the largest class of expenditure in highway maintenance activities.

A variety of personnel assignment and allocation techniques have been used in an effort to hold labor costs down and to use manpower as effectively as possible. These include

- Same working hours as in summer with overtime as necessary,
- Reduced regular hours to compensate for increased premium time,
- Dual shifts based on storm conditions with reversion to single shifts at the end of the storm, and

• Dual shifts for the entire winter season or the portion of the season when most severe storms are expected.

The Pennsylvania Department of Transportation (PennDOT) has used the seasonal dual-shift technique for a number of years for all but 2 of its 11 districts. The beginning and ending dates of the dual shifts vary depending on the area of the state. The hours of dual shifting also vary somewhat, although the most common hours are from 4:00 a.m. to 12 noon for the first shift and from 12:00 noon to 8:00 p.m. for the second shift. Assignment of personnel to the shifts may also vary, but each shift is usually about the same size.

Increasing highway-related costs have caused PennDOT to embark on a number of research projects. In the case of winter maintenance manpower, the department wished to ascertain whether manpower was being used effectively and developed a research project with several clearly identifiable objectives. These objectives were to determine the cost-effectiveness of single- and dual-shift staffing during the winter months, identify maintenance activities that are not snow related and that can be performed during cold weather, estimate the amounts of work that can be accomplished with single and dual shifts, and ascertain optimum winter staffing patterns.

RESEARCH APPROACH

The project objectives could not be achieved satisfactorily until extensive research data had been collected and analyzed. Several methods were used in the collection of these data; they included interviews, questionnaires, statistical analysis, and inspection of department records.

Each assistant district engineer for maintenance and several county maintenance managers were interviewed. During the interview process, it was discovered that there were a number of arrangements for winter shifts. Single shifts, dual shifts, transition periods, skeleton crews, and so on, are all ways in which winter maintenance activities are now being accomplished. These various staffing schedules were examined in terms of efficiency and productivity.

The collection of weather data from the National Oceanic and Atmospheric Administration (NOAA) weather library in Silver Spring, Maryland, was one of the tasks undertaken in this project. With input from the district engineers, three representative weather stations were chosen in each district. Detailed weather data were then gathered for that location for three types of winter: those with light snowfall, average snowfall, and heavy snowfall. Types of winter were selected by recording the amount of snowfall and the number of degree-days for every winter from 1968 to 1980 at the seven National Summary Weather Stations throughout the state. The mean amount of snowfall and the standard deviation were calculated. The average winter was selected as the one having the amount of snowfall closest to the mean. The light winter was selected as the one having the amount of snowfall closest to the mean less one standard deviation. The heavy winter was selected as the one having the amount of snowfall closest to the mean plus one standard deviation.

A detailed weather data form was developed on which the following information was recorded:

- District;
- Representative weather station;
- Winter;
- Month;
- Type of winter;
- Day and date;
- Source weather station for snow, temperatures, and precipitation times;
- Inches of snow;
- Temperature; and
- Beginning and ending precipitation times.

Once this information had been collected, the detailed weather data forms were reviewed and certain inconsistencies were noted. Possible reasons for these inconsistencies were misunderstandings about reporting procedures, actual errors in reporting data, improper recording of information, and so on. Whatever the reasons for the errors, editing was required in order to make the data uniform and meaningful. To avoid bias in the editing, statistically valid procedures were used.

A series of computer programs were written to refine the weather data and calculate hours of work required for winter maintenance. These were as follows:

- Modified Weather Program (MODWP) accounts for instances in which precipitation is shown at below-freezing temperatures during the time period recorded but no snow amount is shown. This is done by defining time of ice storms.
- Storm Clearing Program (STCLP) allows time for clearing of the roadway following a storm.
- Daylight Work Program (DAYWP) determines, at various locations in the state for each day, the time of the day when there is sufficient light to work on site in the mornings and in the evenings.
- Crew Time Program (CRTMP) provides regular work hours, time during morning and evening when it is too dark to work and is not snowing, and premium time required for winter operations.

It was believed that data concerning other states' practices for working during the dark early morning and early evening hours of winter would also contribute significantly to the research data for this project. An appropriate questionnaire was prepared, which was sent to the maintenance directors in 23 states. The states with weather patterns similar to Pennsylvania's and thus thought most likely to furnish useful information were selected. Completed questionnaires were received from each of the 23 states contacted.

RESULTS

Research and analysis were completed on several major topics. These topics included

- Weather patterns,
- Weather severity index,
- Correlation of 1981-1982 computer analysis with actual data,
- Accident analysis,
- Staffing patterns,
- Work analysis (single- compared with dual-shift counties), and
- Description of crew time programs.

Weather Patterns

Cyclonic storms, the familiar low-pressure-pattern storms, are the source of most of the snow and ice conditions with which this analysis is concerned. The storm's intensity is determined by temperature, wind velocity, and precipitation. The real extent of the storm (usually 500 to 1,000 miles in diameter) and the track of the storm determine the region affected as the general pattern moves in relation to the region.

The topography of Pennsylvania--valleys, ridges, plateaus, and mountains--and the orientation of these features add complexity to the weather pattern by producing many local effects, but storm tracks usually follow one or two broad paths west or east of the mountains that bisect the state in a general southwest to northeast direction. The jet stream meanders to the east and west as well as to the north and south, and these meanderings in combination with the effects of the mountain ranges tend to determine the storm tracks because the jet stream steers the storm and the mountains tend to block it.

Storms are air in motion, so the impeding of storm movement by mountains would be expected, but there are other less obvious factors. Topography, that is, the relative elevations of the earth's surface, produces distinct effects as storms proceed over higher elevations or move from higher to lower elevations. Lowlands or bowls frequently experience significantly different weather than adjacent or surrounding areas because of the effect of topography. Topography appears to modify the weather in the central mountain region by reducing the total or the frequency of significant snowfall in winter.

Cold air, if it remains over any lake long enough in transit, can become nearly saturated. On reaching shore, the air is lifted up the hills that surround the lake, particularly to the southeast, and cooling causes condensation and precipitation in the form of snow. Under some conditions, large cumulus clouds form because the air is warmed enough over the lake to create large-scale convection and significant snowfall will occur. Added to the topographic effects in cyclonic storms, this set of conditions provides the area of extreme northwest Pennsylvania with some of the largest and most frequent snowfall.

A general topographical classification of areas in Pennsylvania by winter weather severity in terms of snow and ice (in descending order) is as follows: upslopes, uplands, plains, or bowls. A generalized map of these areas is shown in Figure 1.

Weather Severity Index

Completely objective criteria for determining the severity of a particular winter are difficult to establish because of the interaction of weather elements: temperature, precipitation, wind, solar insolation, and so on. Before the CRTMP was completed, a subjective method of evaluating the severity of a given winter was established by using only the total amount of snowfall. Winters were selected as light, average, or heavy based on relative total winter snowfall amounts.

On completion of the CRTMP, it was noted that the relative amounts of premium time that were incurred in these winters did not correspond to the winter classification. As every engineer responsible for winter maintenance operations in the snow belt instinctively realizes, the depth of snow that has fallen during any one winter may not indicate the severity of that winter in terms of expenditures. As a result, the concept of a winter severity index (SI) based on total meteorological data was developed. The information required was obtained by using the programs written for this project.

The SI developed from this data is

$$SI = S + 2M + H + T - (C/2) + R \quad (1)$$

where

- S = total inches of snowfall in the period,
- M = number of days with snowfall of 1 to 6 in.,
- H = number of days with snowfall greater than 6 in.,
- T = number of days with a maximum temperature above 32° F and a minimum temperature below 32° F,
- C = number of days with temperatures below 32° F, and
- R = total hours in the period when snow or ice occurs.

The total single-shift premium hours and the SI for the full winter period (November 1 to March 31 + 1) for each representative weather station were computed and tabulated. These values were for the same stations and period. Figure 2 shows the plot along with the result of a linear regression analysis. The correlation coefficient is .94, which indicates a high degree of correlation between SI and the CRTMP results. The equation of the linear fit curve is Y = -37.9 + .8X.

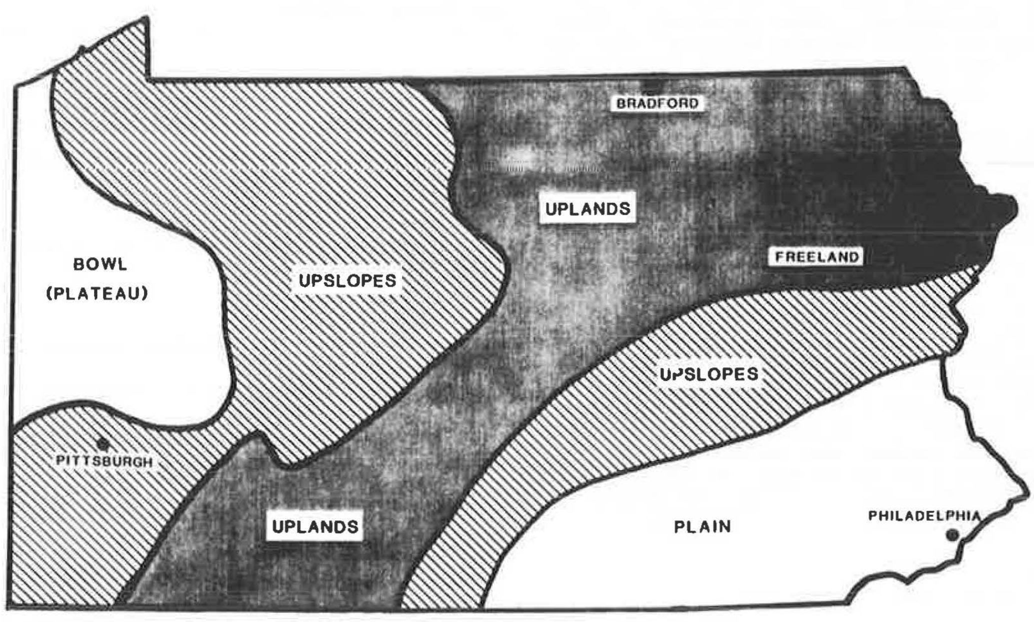

FIGURE 1 General topographical classifications of areas in Pennsylvania.

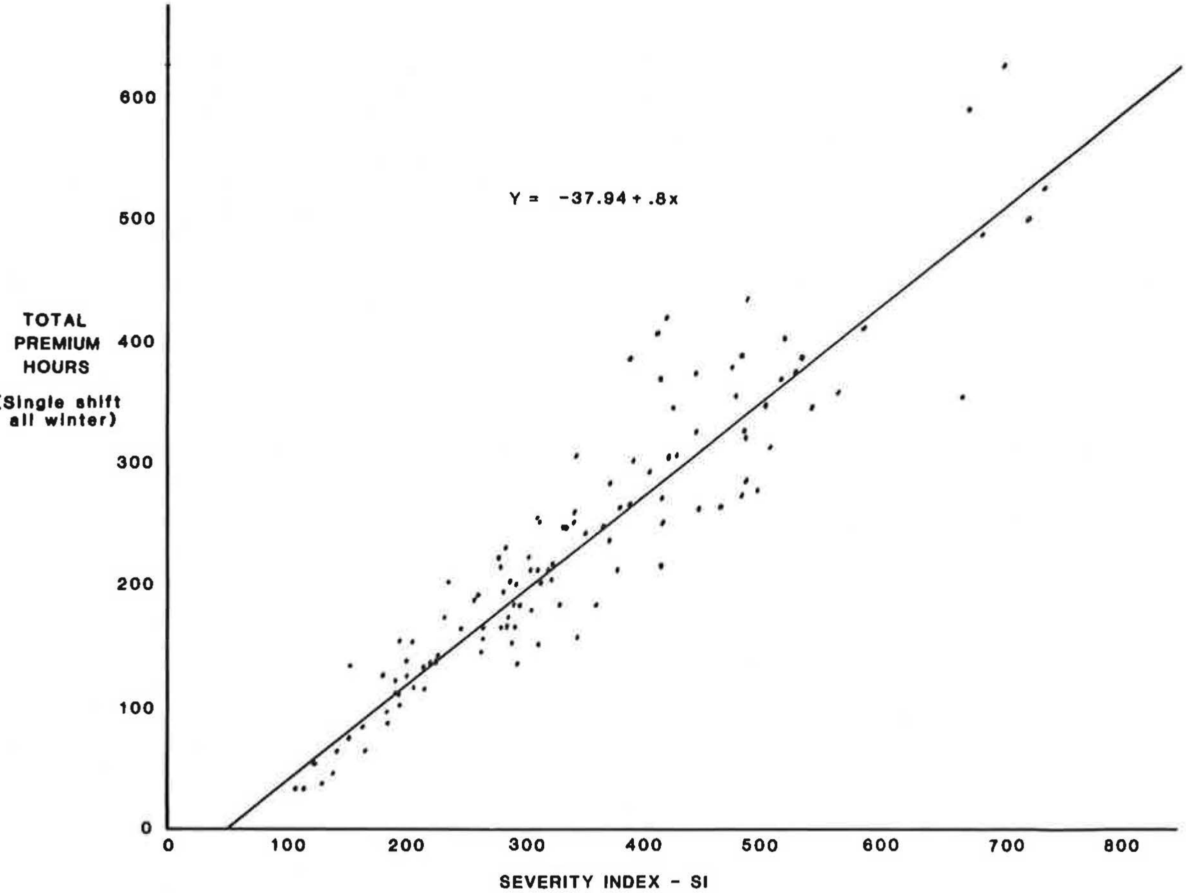

FIGURE 2 Severity index.

In the section of this paper on correlation of the 1981-1982 computer analysis with actual data, it was established that the CRTMP results showed a reasonable correspondence with actual data. The correlation of the SI with the analysis program results indicates that the SI provides a valid indicator of premium-time requirements.

The SI for any winter can be calculated, and with the linear relationship in Figure 2, a corresponding estimate of premium hours can be determined. To develop Figure 2, the SI was computed for the whole winter period and the premium hours were correlated for the same period. The same technique can be used to evaluate a portion of the winter to achieve a similar correlation. This might be useful in identifying and correlating the more severe midwinter period.

The components of the SI were then examined to determine whether the index could be further refined. This examination showed that the total hours of snow or ice in the period is the most significant component. Some components such as total snowfall for the winter had a lesser effect on the index. However, the correlation was not as good when the total hours of ice and snow alone was used as an index. It is believed that a much more extensive statistical analysis might refine the SI, because it was developed empirically.

Correlation of 1981-1982 Computer Analysis with Actual Data

The actual or reported regular and overtime hours charged to highway maintenance in the winter period between November 1, 1981 and April 11, 1982, for each county were made available to permit a comparison with the results of the CRTMP. The 1981-1982 weather for this same period was used as a data base.

A representative weather station for each county was selected on the basis of information provided by the county maintenance managers and a subjective evaluation based on weather patterns and topography. A computer analysis of 1981-1982 weather data was made for each county with weather analysis parameters held fixed and shifting periods varied to coincide with the district and county managers' stated practices. The fixed weather analysis parameters were an ice temperature of 28° F, icing times of 8:00 a.m. and 8:00 p.m., light storm with less than 4 in. of snow, and heavy storm with 4 in. or more of snow. The storm clearing times were held fixed at 2 hr for light storms and 3 hr for heavy storms on the basis of information provided by district managers. The shifts were adjusted for single- and dual-shift periods, and shift times actually used were obtained from the maintenance managers. The small difference in the length of time represented by weather records and work activity records, sick leave time, vacation time, and other factors that might cause some predictable disparity between results obtained from the CRTMP and actual records were considered and appropriate adjustments made.

The CRTMP output provided a total of regular crew hours and overtime crew hours for each shift period. Crew time was chosen to be the factor developed rather than individual time, which is too awkward and lends nothing to accuracy. For comparisons with the 1981-1982 records, however, crew time had to be converted to individual time because the department records are kept on that basis. The total regular work hours and total overtime hours for each shift period, and in turn for the entire winter period (November 1 to March 31), were computed for each county on the basis of the number of employees per shift for regular work hours and overtime hours, respectively. The total personnel assigned to overtime shifts in the county corresponds to the number of trucks plus the number of crews unless some additional information indicated otherwise. This implies only one operator for each truck plus a foreman for each crew in the normal overtime arrangement. It was recognized that not every truck is operable all the time and that some loader, grader, or laborer manpower is utilized. Further adjustments such as reducing the number of personnel on overtime because of the use of patrols were made when such information was available.

The computed regular hours show relatively good correspondence with reported regular work hours because both are basically a product of the number of employees times 7.5 regular workday hours. Unknown augmentations of personnel or high percentages of personnel on leave, however, directly affect the reported regular hours.

The variability between the reported overtime hours and the computer overtime hours is a result of several factors, including the actual manpower level, management decisions on callout and other decisions, the accuracy of the CRTMP, and how accurately the input weather data reflect the condition seen by the managers.

The comparisons of regular and overtime hours alone do not reflect as accurate a measure as the total or reported regular and overtime hours compared with the total and computed regular and overtime hours for each county. Statistically it appears that on average the number of personnel on shifts are correct, and uniform practice exists regarding callout, cleanup times, and so on. Thus, on the average, variable weather severity is the major factor in determining the total hours.

The overtime hours used in this comparison are only those reported for providing winter traffic services--plowing, spreading antiskid materials, and storm cleanup--on the basis that overtime would only be authorized for these particular functions.

The percentage differences between the reported total of regular and premium hours and the computed total of regular and premium hours have a mean value of -2.92 and the deviation is ±10.94; thus the computed total of regular and overtime hours is less than the reported total by -2.92 percent on average and is within ±10.94 percent of the average of -2.92 percent, that is, between -13.86 and 8.02 percent of the reported total, in 68.26 percent of the cases.

The results indicate that the CRTMP is reliable.

Accident Analysis

Data were provided regarding accidents that occurred on snow- or ice-covered roads in the winters of 1979-1980 and 1981-1982. These data facilitated an analysis in which it was hoped that it could be determined whether counties using only single shifts had different accident rates from those using dual shifts.

No statistically definitive basis for identifying a relationship between accident rates and single or dual shifts could be found. It was concluded that weather variability is likely to mask any relationship that may exist between shift patterns and accident rates. Further, the sample size in relation to the range of variables was believed to be too small for reliable analysis.

Staffing Patterns

The cost-effectiveness of dual-shift staffing patterns as opposed to the exclusive use of single-shift staffing patterns was examined in relation to weather severity. On the basis of a statewide average, it was decided that a single-shift crew of 13 persons with 5 trucks available was representative. In order to operate dual shifts, it would be necessary to augment the initial 13-person single-shift crew with a minimum of a foreman and split the personnel evenly into two 7-person shifts. These crews may not be ideal or even practical in many instances, but they are possible and will illustrate the method of computing shift cost comparisons.

The average hourly wage was assumed to be the state average of $8.15/hr. The dual-shift differential of $0.35/hr was applied to dual-shift cost. The single- and dual-shift premium multiplier of 1.5 was applied. The hourly rates were as follows:

1. Single shift: $8.15/hr,
2. Premium single shift: 1.5 x $8.15 = $12.23/hr,
3. Dual shift: $8.15/hr base rate + 0.35 shift differential = $8.50/hr, and
4. Premium dual shift: 1.5 x $8.50 = $12.75/hr.

The single-shift crew of 13 persons thus costs 13 x $8.15 = $105.95 per regular shift hour. The dual-shift crew of 7 persons costs 7 x $8.50 = $59.50 per regular shift hour. The premium-time crew for both single and dual shifts was established at 7 persons for this example for consistency and comparison. The single-shift crew for premium time thus costs 7 x $8.15 x 1.5 = $85.58/hr. The dual-shift crew for premium time costs 7 x $8.50 x 1.5 = $89.25/hr.

The analysis program produces for any given calendar period and shift arrangement a total of regular shift hours and a total of premium hours. The total of regular hours excludes any hours worked on holidays and weekends in the period and is based on a 7.5-hr work day. The premium-time total accounts for all snow and ice time over 8 hr outside of regular shift hours on regular work days plus the impact of holidays and weekend days in the period.

Multiplying the appropriate total of hours by the associated hourly crew cost gives the total of regular-hour cost or premium-hour cost for the period, and the total of these two costs is then the total cost for the period.

These costs for our example are as follows:

1. Total single-shift regular-hour crew cost = $105.95 x total regular single-shift hours,
2. Total single-shift premium-hour crew cost = $85.58 x total premium single-shift hours,
3. Items 1 and 2 = total single-shift cost in the calendar period considered,
4. Total dual-shift regular-hour crew cost = $59.50 x total regular dual-shift hours,
5. Total dual-shift premium-hour crew cost = $89.25 x total premium dual-shift hours, and
6. Items 4 and 5 = total dual-shift cost in the calendar period considered.

The total cost of operating throughout a full winter with the single-shift crew arrangement described in the foregoing was compared with the total cost of the same winter when the personnel were augmented by a foreman and split into dual-shift crews. Two dual-shift periods were selected as representative of the dual-shift period used by most maintenance districts; these were the calendar periods December 1 through February 28 and December 16 through March 15. These costs were computed for each district by using the weather data from the representative weather station for that district in light, average, and heavy winters plus the data for the 1981-1982 winter.

The use of dual-shift periods can be justified on a cost basis in some instances. When winter severity (the incidence of snow or ice conditions) results in the requirement for so much single-shift premium time in a calendar period that by converting to dual-shift operation the reduction in premium hours required on dual shift is enough to compensate for the added shift differential and higher overtime hourly pay, dual shifts should be considered. In this example, the added cost of the additional foreman was included in the total cost.

In fact, the reduction of premium hours required to compensate for the added cost of extra personnel and the shift differential pay can be computed and is a function of the total single-shift premium time in the calendar period. For the periods chosen, the number of premium hours saved by going to dual-shift staffing must exceed a minimum of 70 and be at least about one-third of the total single-shift premium hours in the period. Other ratios will apply if the number of persons or the calendar periods are changed.

In summary, it can be shown that dual shifting may be cost-effective in counties with either consistently frequent snow and ice conditions or heavy winters if the dual-shift calendar period is chosen so that the number of premium hours saved by the dual shifting is sufficient to offset the cost of added personnel and shift differential pay for dual shifts.

Cost is not the only factor in evaluating the merits of dual shifting. Safety, efficiency, and the related productivity are considerations that may outweigh cost alone. Consider the case of District 2, Bradford Weather Station, winter of 1976-1977, when in the period of 13 weeks from December 1, 1976 through February 28, 1977 the analysis program showed that a single-shift crew would have been required to work 411 premium hours. This is an average of 31 premium hours per week. Assuming that there would have been two premium-hour shifts with premium time equalized, each man would have been required to work more than 15 premium hours each week. The extra hours make the average work week about 53 hr long. Because the weather is not evenly distributed, it can be assumed the requirement would be even higher in some weeks. The record shows 6 consecutive weeks in this period when at least 26 hr of premium time were required in the regular work week. This amounts to more than 50 hr per person in 5 days. In addition, three weekends in the period added in excess of 20 hr each, making 2 weeks of the period exceed 60 hr per man in the 7-day week. At this point the employees are putting in so many hours a day on a continuing basis that efficiency and safety may be affected. Dual shifting in this case reduces the premium hours to 261 for the period or 20 hr per week for an average of 10 hr per man, which is an average of 47.5 hr in a 5-day week. The demands of weekend premium time remain. The effect of reducing overtime demands on personnel and the benefit to efficiency and safety must be weighed against cost. In this particular case, the change to dual shifting has the added advantage of reducing cost. This is not always the case. Though weather variability will determine the actual effect as will the dual-shift hours, the conversion from a single shift from 8:00 a.m. to 4:00 p.m. to a dual shift from 4:00 a.m. to 12:00 noon and noon to 8:00 p.m. can statistically be expected to reduce premium hours by 22 percent. Thus when the single-shift premium hours in a calendar period become so great that they will require more than a desired amount of premium time per person per week, a conversion to dual shifts can be expected to provide a 22 percent reduction in premium time if the shift hours are as just stated.

It appears, as a value judgment, that average overtime of more than 8 or 10 hr a week, particularly when it may occur in the regular work week of 5 days, begins to affect personnel efficiency, safety, and morale. These then become considerations other than cost for converting to dual shifts.

Dual shifts produce other problems with regard to productivity and safety. The midwinter period when dual shifts are most likely to reduce premium time, for efficiency and safety reasons, as well as reduce cost is also the time when the greatest portion of working time will be in the dark. The computer analysis provides a total of the dark time in any period, adjusted as desired for morning and evening twilight, and the effect of shift hours on the total is readily apparent. The total reflects only those regular work days on which snow or ice does not occur, so it is directly related to the productivity of time not used for snow and ice control. During this time, the efficiency, if not the productivity, of personnel will be adversely affected by work in the dark. The analysis of work hours by function for single-shift compared with dual-shift counties, discussed in the section on work analysis, gives a measure of this effect. In addition, safety precludes the undertaking of some activities, such as pavement patching, in the dark hours. The decision to dual-shift must be tempered by consideration of the reduced efficiency, productivity, and safety of what can be accomplished in the dark, because this time period may constitute nearly half the available man hours on a given dual-shift day and perhaps as much as 30 percent of the total available man hours in a dual-shift calendar period.

The best practice regarding dual shifts seems to be that when the winter severity will require more single-shift premium time per man than is considered efficient and safe and/or the total premium hours in any selected calendar period is large enough so that dual shifts will reduce premium hours enough to fully compensate for extra employees and shift differential, dual shifts should be used for that calendar period. At this point weather severity has made snow and ice control paramount, and any loss of efficiency or production for other activities because they are being performed in the dark is less important.

Unfortunately, within a current winter season the evaluation of the severity of the winter is quite subjective. The climatic record and the use of a premium-hour threshold appear to offer the only means of establishing the best dual-shift period for a county.

On the basis of the analysis completed and the considerations presented, it was concluded that there are some counties that should definitely utilize dual shifts for a midwinter calendar period, there are some counties that might benefit from the use of dual shifts for a midwinter calendar period in some winters, and there are those counties that definitely will not benefit from using dual shifts in any period of any winter. This is shown graphically in Figure 3 in which the labor cost of winter maintenance operations for single and dual shifts is plotted against three types of winters--light, average, and heavy--for four representative weather stations. (It should be noted that the curves in the four plots are not consistently shaped because every winter is unique in some respect and the average winters do not bear the same relationship to the light and heavy winters for each weather station.) The plots indicate that the following shift arrangements would be appropriate for counties having the

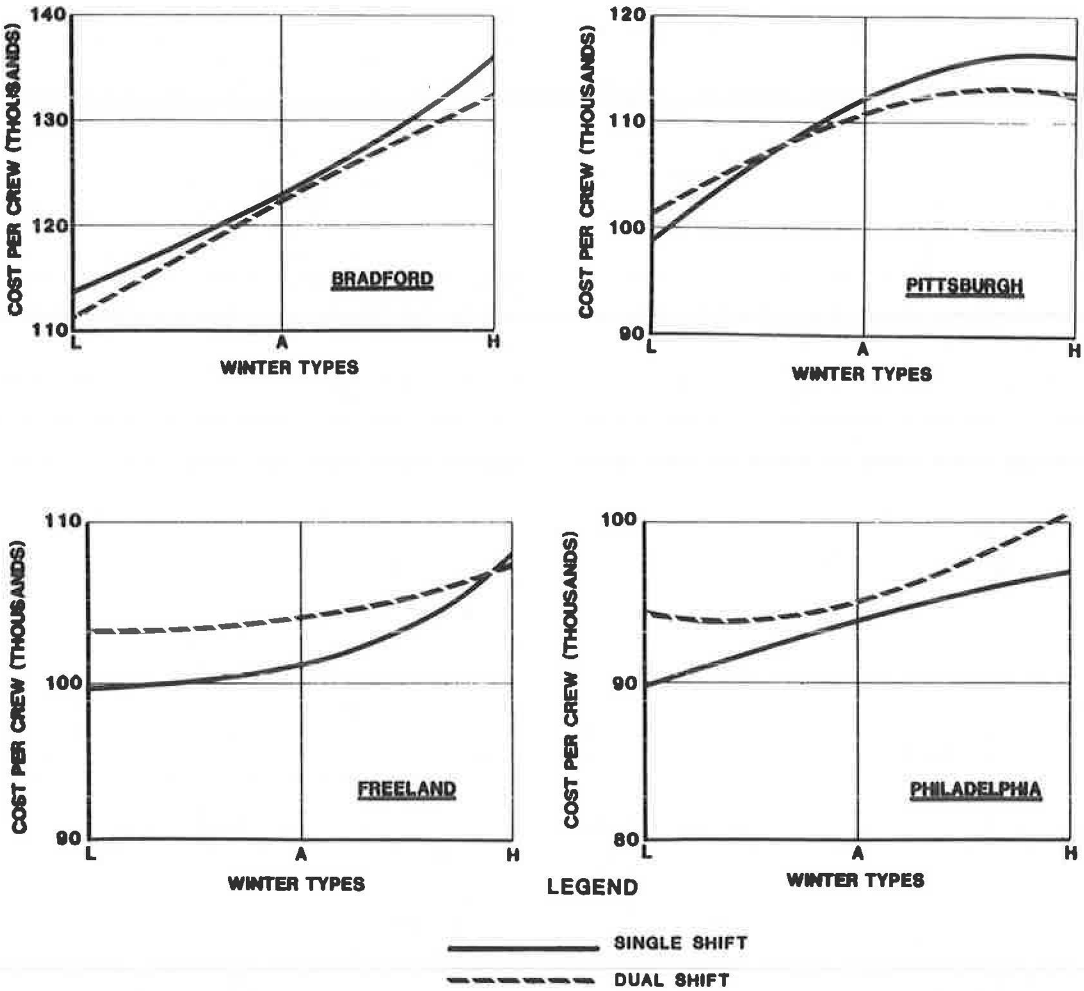

FIGURE 3 Staffing patterns: single- versus dual-shift cost comparison in dollars for four representative weather stations.

same weather as the representative weather stations indicated in Figure 3:

1. Bradford: Dual shifts are cost-effective and should be used,
2. Pittsburgh: Dual shifts are generally cost-effective and should be used for the major part of winter,
3. Freeland: Dual shifts may be cost-effective and should probably be used for the part of winter when severest weather is expected, and
4. Philadelphia: Dual shifts are not cost-effective and should not be used.

There is a similarity between the areas in which dual shifts are likely to be cost-effective, may be cost-effective, or are not likely to be cost-effective and the respective topographic areas discussed earlier--upslopes, uplands, and plains or bowls (Figure 1). This is helpful as a general guide as to which counties fall into each dual-shift category.

In this section procedures have been demonstrated for developing a staffing concept for single-shift and dual-shift crews and the premium-time crews required for each. The computer programs developed in this research have a large number of variable inputs and items to be selected on the basis of intimate knowledge of specific topographic areas, crew sizes, times actually required for clearing after storms, most appropriate representative weather stations, management decisions, and other factors, so it was considered impossible to respond to every county manager's concerns regarding staffing patterns and optimum working hours. As a result each district was furnished with diskettes containing weather data pertinent to that district and the computer programs so that the programs could be run in the district office on its personal computer.

Work Analysis

PennDOT provided data itemizing the hours charged to specific maintenance activities in each county for the period November 1, 1981 through April 11, 1982. Three pairs of counties, one using single shifts and one using dual shifts in each pair, were selected for comparison of time use. The selections were made on the basis of traffic counts, daily vehicle miles, urban population, and proximity so that similar weather would be expected.

Obviously, winter service hours reflect the first-priority requirements of the season. The amount of total time charged to winter services exceeded 50 percent in dual-shift counties, whereas it was somewhat less than 50 percent in single-shift counties; differences between pairs ranged from 9.3 to 16.9 percent of total hours. Differences in management, topography, and weather between the counties apparently account for such variations.

```
PROGRAM FOR MODELING STAFFING PATTERNS   FOR WINTER 11/01/76 THRU 03/31/77
                              DISTRICT  5   LEHIGH
                            * WEATHER STATION *
  ALLENTOWN                  STROUDSBURG

               [1] ICE STORM TEMPERATURE (°F) :           30
               [2] MORNING ICE TIME (HHMM):               0800
               [3] EVENING ICE TIME (HHMM):               1700

               [4] DATE  FROM(MMDDYY):                    121576
               [5] TO  (MMDDYY):                          022877
               [6] NUMBER OF SHIFTS:                      1
               [7] FIRST BEGIN REGULAR WORK DAY (HHMM):0800
               [8] LAST END REGULAR WORK DAY (HHMM):   1600
               [9] LIGHT STORM CLEARANCE (HHMM):          0130
               [0] HEAVY STORM CLEARANCE (HHMM):          0230
                   TOLERANCE TIME IN MIN [A] 00    [P]    00

 ----------------------------- VALID COMMANDS ----------------------------
<O> START OVER                 <C> CREW HOURS REPORT     <Q> QUIT
<H> HELP WITH COMMANDS         <S> SUMMARY REPORT        <W> WEATHER STA.
<D> CHANGE DISTRICT            <L> MOD. DATA
What is your choice?
```

FIGURE 4 Program input display.

Results from the computer programs using the winter of 1981-1982 were combined with the data received from PennDOT for that winter to analyze the hours devoted to various maintenance activities. Because the computer programs furnished a complete summary of the weather and the hours of dark time when work on the roadway could not be performed, a number of useful comparisons could be made and conclusions, or at least inferences, drawn from them.

The analysis showed that dual-shift counties charge a larger percentage of total hours to winter services than do single-shift counties. It was concluded that this is at least in part a consequence of more severe weather in the counties compared. Dual-shift counties suffer a substantial penalty caused by dark hours compounded by weather factors in that the opportunity to perform other functions than winter services in light hours with reasonable safety and efficiency is significantly reduced. On dual shifts more than on single shifts, the hours when darkness, weather conditions, and safety preclude performing higher-priority work appear to be used on low-priority tasks. Dual shifts would therefore be limited to those areas and periods where the need to reduce overtime due to fatigue is apparent, a possible cost reduction may result, and the winter service activities are paramount to reduced maintenance productivity.

CRTMP Operation and Results

The CRTMP has the capability of providing a total of regular shift hours and premium hours that would accrue in any winter for which weather data are available and in accordance with the parameters selected. The parameters that may be selected are displayed on the computer terminal and may be changed through simple, conventionally recognized procedures.

The input display seen on the computer terminal is shown in Figure 4. The header (block 1, line 1) exhibits the inclusive period of weather data that was last placed in the Modified Weather File, the working file. The second line displays the maintenance district number that has been selected. The fourth line bears the names of the representative weather stations for the district selected. On the actual terminal the name of the weather station selected as a weather data base appears brighter than the others.

Block 2 of the input display has three lines pertaining to ice parameters. Line 1 displays the ice storm temperature in degrees Fahrenheit below which ice formation is considered to occur and which is variable to account for salting, solar heating, and traffic effects. Line 2 displays the morning ice time in hours and minutes, the time after which ice is not expected to form unless the maximum temperature is equal to or less than the ice storm temperature and which may be varied to account for effects such as sunrise, traffic volume, and shift times. Line 3 displays the evening ice time in hours and minutes, the time before which ice is not expected to form unless the maximum temperature is equal to or less than the ice storm temperature and which may be varied to account for daytime heating, traffic volume, and shift schedules.

Block 3 contains lines as follows:

Line 4 indicates the beginning date of the winter period to be analyzed in accordance with the parameters selected on lines 1 to 3 and 6 to 11;

Line 5 indicates the last day in the period to be analyzed in accordance with the parameters selected;

Line 6 displays 1 or 2 as selected for single or dual shifts;

Line 7 displays, in hours and minutes on a 24-hr clock, when the first regular shift starts;

Line 8 displays, in hours and minutes on a 24-hr clock, when the last regular shift ends;

Line 9 displays in hours and minutes the time added to the last hour of precipitation to allow for cleanup of a snowfall of less than 4 in.;

Line 10 displays in hours and minutes the time added to the last hour of precipitation to allow for cleanup of a snowfall of 4 in. or greater;

Line 11, Tolerance Time in Minutes, displays (A) the number of minutes before official sunrise to be subtracted from the time from beginning of the regular workday to sunrise and (P) the number of minutes of evening twilight to be subtracted from the time from sunset to the end of the regular workday.

Below the boxes are the valid commands designated by letter keys, which are self-explanatory.

Several reports are provided by the program:

- Crew Hours Report (Figures 5 and 6): Two reports are provided to show the substantial amount of dark time, indicated by Total AMTime and Total PMTime on the reports, that occurs when dual shifts are used compared with when single shifts are used. Dark time is only calculated on days when it does not snow.
- Summary Report (Figure 7): The winter SI is

```
DATE OF RUN FRI, SEP 07 1984 AT 10:37:04

  DISTRICT:  5      LEHIGH
  WEATHER STATION: STROUDSBURG
  DATE RANGE: 12/15/76 THRU 02/28/77
  ICE STORM TEMPERATURE  30 F
  MORNING ICE TIME:   8:00          EVENING ICE TIME:  17:00
  NUMBER OF SHIFT: 1
  FIRST BEGIN REGULAR WORK DAY:   8:00    LAST END REGULAR WORK DAY:  16:00
  LIGHT STORM CLEARANCE:  1:30     HEAVY STORM CLEARANCE:    2:30
  TOLERANCE TIME IN MIN:  0 AM      0 PM
  $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

	TOTAL REG	TOTAL AMTIME	TOTAL PMTIME	TOTAL PRTIME
*** TOTALS ***	390:**	0:00	0:00	139:00

FIGURE 5 Crew hours report: single shift.

```
DATE OF RUN FRI, SEP 07 1984 AT 10:41:14

  DISTRICT:  5      LEHIGH
  WEATHER STATION: STROUDSBURG
  DATE RANGE: 12/15/76 THRU 02/28/77
  ICE STORM TEMPERATURE  30 F
  MORNING ICE TIME:   8:00          EVENING ICE TIME:  17:00
  NUMBER OF SHIFT: 2
  FIRST BEGIN REGULAR WORK DAY:   6:00    LAST END REGULAR WORK DAY:  20:00
  LIGHT STORM CLEARANCE:  1:30     HEAVY STORM CLEARANCE:    2:30
  TOLERANCE TIME IN MIN:  0 AM      0 PM
  $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

	TOTAL REG	TOTAL AMTIME	TOTAL PMTIME	TOTAL PRTIME
*** TOTALS ***	780:00	39:15	99:07	108:30

FIGURE 6 Crew hours report: double shift.

```
DATE OF RUN FRI, SEP 07 1984 AT 10:37:01

  DISTRICT:  5      LEHIGH
  WEATHER STATION: STROUDSBURG
  DATE RANGE: 12/15/76 THRU 02/28/77
  ICE STORM TEMPERATURE  30 F
  MORNING ICE TIME:   8:00          EVENING ICE TIME:  17:00
  NUMBER OF SHIFT: 1
  FIRST BEGIN REGULAR WORK DAY:   8:00    LAST END REGULAR WORK DAY:  16:00
  LIGHT STORM CLEARANCE:  1:30     HEAVY STORM CLEARANCE:    2:30
  TOLERANCE TIME IN MIN:  0 AM      0 PM
  $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

121576 - 022877 DIST. 5 LEHIGH

SNOW STORM RANGE	SAT	SUN	MON	TUE	WED	THR	FRI	TOTAL
0.1" TO < 1.0"		1					2	3
1.0" TO < 6.0"	4	2	1	2	1		1	11
6.0" >			1					1

HOUR	NO. TIMES SNOWING	NO. TIMES ICING	HOUR	NO. TIMES SNOWING	NO. TIMES ICING
0000 - 0100	6	0	1200 - 1300	2	1
0100 - 0200	4	0	1300 - 1400	2	1
0200 - 0300	4	0	1400 - 1500	3	0
0300 - 0400	3	0	1500 - 1600	3	2
0400 - 0500	5	0	1600 - 1700	4	3
0500 - 0600	2	0	1700 - 1800	2	5
0600 - 0700	3	0	1800 - 1900	3	4
0700 - 0800	3	0	1900 - 2000	2	3
0800 - 0900	3	1	2000 - 2100	1	7
0900 - 1000	4	2	2100 - 2200	2	7
1000 - 1100	1	1	2200 - 2300	2	6
1100 - 1200	2	0	2300 - 2400	2	6

```
TOTAL SNOW FALL (IN INCHES):      26.26  (     26.60)  NO. OF ICE STORM       0
NUMBER DAYS MIN TEMP BELOW 32 & MAX TEMP ABOVE 32        32
NUMBER DAYS MAX & MIN TEMP BELOW 32       32
****************************************
*  W FACTOR =      182.600 24 hrs  *   *
*  W FACTOR =      154.600 1600 - 0800 *
****************************************
```

FIGURE 7 Summary report.

DATE OF RUN FRI, SEP 07 1984 AT 10:37:58

DISTRICT: 5 LEHIGH
WEATHER STATION: STROUDSBURG
DATE RANGE: 12/15/76 THRU 02/28/77
ICE STORM TEMPERATURE 30 F
MORNING ICE TIME: 8:00 EVENING ICE TIME: 17:00
NUMBER OF SHIFT: 1
FIRST BEGIN REGULAR WORK DAY: 8:00 LAST END REGULAR WORK DAY: 16:00
LIGHT STORM CLEARANCE: 1:30 HEAVY STORM CLEARANCE: 2:30
TOLERANCE TIME IN MIN: 0 AM 0 PM
$$$

				TOTAL REG	TOTAL AMTIME	TOTAL PMTIME	TOTAL PRTIME
12/15/76	WED		0.00	7:30	0:00	0:00	0:00
12/16/76	THR	ICE	0.00	7:30	0:00	0:00	6:00
12/17/76	FRI	LT SNOW	0.70	7:30	0:00	0:00	2:30
12/20/76	MON	ICE	0.00	7:30	0:00	0:00	7:00
12/21/76	TUE		0.00	7:30	0:00	0:00	0:00
12/21/76	WED		0.00	7:30	0:00	0:00	0:00
12/22/76	THR		0.00	7:30	0:00	0:00	0:00
12/23/76	FRI		0.00	7:30	0:00	0:00	0:00
12/25/76	SAT	ICE	0.00	0:00	0:00	0:00	4:00
12/26/76	SUN	LT SNOW	3.50	0:00	0:00	0:00	10:00
⋮			⋮	⋮	⋮	⋮	⋮
02/18/77	FRI		0.00	7:30	0:00	0:00	0:00
02/20/77	SUN	LT SNOW	1.00	0:00	0:00	0:00	2:30
02/21/77	MON	HVY SN	6.00	7:30	0:00	0:00	3:30
02/22/77	TUE		0.00	7:30	0:00	0:00	0:00
02/23/77	WED		0.00	7:30	0:00	0:00	0:00
02/24/77	THR		0.00	7:30	0:00	0:00	0:00
02/25/77	FRI		0.00	7:30	0:00	0:00	0:00
02/28/77	MON		0.00	7:30	0:00	0:00	0:00
*** TOTALS ***				390:**	0:00	0:00	139:00

FIGURE 8 Detailed report.

calculated by using two time parameters and is shown at the bottom of the report as the W-factor.

- Detailed Report (Figure 8).

CONCLUSIONS

A number of conclusions were reached and recommendations made as a result of the project described in this paper. Included among these were the following:

1. Weather varies greatly in Pennsylvania, and even adjacent counties experience different weather conditions as the result of storm movements and terrain features. Consequently, it was recommended that no attempt be made to establish a standard staffing pattern.
2. The winter SI provides a means of approximating the relative severity of winters. The correlation with actual data as well as with the CRTMP results makes it useful for evaluating performance.
3. The CRTMP provides reliable premium-time requirements when compared with the weather data and the input variables. Availability of the program in district offices will permit an almost limitless number of variables and staffing patterns to be tried in a short time at very little expense.
4. Snow removal and ice control usually cannot be deferred and thus take precedence over other maintenance activities. The impact of this requirement on the scope, productivity, and efficiency of other tasks cannot be completely avoided or mitigated.
5. The analysis comparisons and interviews conducted as part of the research indicate that the personnel at all levels in PennDOT are generally conscientious, dedicated individuals who have demonstrated ingenuity, cost consciousness, flexibility, and determination in an effort to get the job done as efficiently as possible with the available information and resources. Obviously, these individuals have already found effective solutions to many difficult problems.
6. Survey results show that on a nationwide basis, during the dark hours work other than performing winter maintenance is rarely done in the traveled way except under very unusual or emergency circumstances. As a result, dual shifts should only be used when genuinely appropriate as discussed elsewhere in this paper.
7. Dual-shift operation for at least part of the winter season can be more economical than single shifts in some districts or counties, and specific recommendations were provided to PennDOT.

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