Cost-Effective Snow and Ice Control for the 1990s

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Road weather information systems (RWISs) are now widely used operationally by road masters to determine when to use deicing chemicals on roads. Data from such systems can also be used to assess the cost-effectiveness of RWISs. To account for the variation in winter weather from year to year (temporal) and across an area (spatial), three winter severity indexes are examined that can be compared with winter maintenance expenditures.

The worldwide introduction and use of road weather information systems (RWISs) has continued unabated since the last Standing International Road Weather Commission conference in Tromsö, Norway, in 1990. Many systems are also coming to the end of their 10-year design lives and are being upgraded or replaced. Table 1 shows the latest estimated state of play in the number of outstations in each country, the amount of thermal mapping conducted, and whether there is a computer link to weather services.

This paper will attempt to assess whether the cost-effectiveness of snow and ice control has increased for those authorities that have introduced RWIS, and whether the situation is likely to change in the 1990s.

The decision to install an RWIS will not be discussed in detail here; it is assumed that most highway authorities will have installed systems by the year 2000. The COST 309 Final Report concludes that "despite relatively high installation costs the implementation of a road weather system will soon reap benefits in terms of better safety, long term cost savings, optimum response to critical weather situations and minimising of environmental damage" (*1*,p.145). The draft SHRP H207 final report concludes that

> every SHA (State Highway Authority) which spends more than $1 million annually for snow and ice control should consider acquiring RWIS to assist in snow and ice control.
>
> An RWIS which blends data inputs from sensors and road thermography into detailed (road weather) forecasts tailored to the needs of a snow and ice control manager offers the opportunity for a significant return on the investment at [benefit/cost ratio] close to 5, yet with significantly improved level of service on the roads and greatly decreased frequency of decision errors. (*2*)

This cost-benefit ratio is identical to that found in Finland as reported in the COST 309 report: "So the cost/benefit ratio is about 1/5 on Kymi road district. In respect of the climate and traffic the Kymi road district represents typical road district in Finland" (*1*,p.90).

RWIS can be used in two main ways: to aid operational decisions on a night-by-night basis and to help management appraisal of overall effectiveness at the end of winter. Most RWISs are installed for operational purposes, and little attention has been paid to management appraisal of their effectiveness. Sophisticated software for operational purposes is available with all systems, but little software has been developed for management; most RWISs have archive facilities, but all too often these facilities are not used properly and data are just filed away on disk. This paper examines what climatological information produced by RWIS is likely to be useful for assessing the severity of a winter, the cost-effectiveness of an RWIS, and the accuracy and effectiveness of an RWIS weather-forecasting service.

WINTER SEVERITY INDEX

Climate variability means that no two winters are ever the same. The main weather parameters that affect winter maintenance are road-surface temperature (below 0°C), precipitation (especially snow), and humidity (frost formation). In an ideal world these parameters could be used to assess the severity of a winter. Unfortunately, road-surface temperatures have been measured only in recent years and climatologists like to have a 30-year average with which to compare a given winter. Air temperature therefore must be used if a long-term average is required, such as 1961–1990. Humidity is not measured reliably at many sites, and data are not readily available in most countries. Data on depth of snowfalls and the number of days with snow cover are available in most countries.

The following winter indexes have been used for the management of snow and ice control. All of them normally consider the period of November 1 to March 31 (151 days, or 152 in a leap year) as winter.

Hulme Index

The Hulme index (*3*) has been modified by Thornes (*4*) to show the variations in winter index about the average, which is set at zero. Thus negative scores represent a colder-than-average winter, and positive scores, a warmer-than-average winter. This is designed to be simple for engineers and politicians to understand. The index is calculated using the following formulae:

$$WI = (10 * T) - F - (18.5 * S)^{0.33} \pm C \qquad (1)$$

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TABLE 1 Worldwide RWIS Installation

Country	Thermal Mapping Km	Road Weather Stations No.	Computer Weather Network
Europe			
Austria	0	280	none
Belgium	0	0	none
Denmark	4000	220	yes
Finland	500	150	yes
France	750	200	yes
Germany	200	160	yes
Holland	3000	153	yes
Italy	0	30	none
Luxembourg	200	20	none
Norway	3500	50	yes
Spain	0	0	none
Sweden	12,000	550	yes
Switzerland	100	200	yes
United Kingdom	38,000	520	yes
North America			
U S A	1000	350	yes
Canada	400	10	yes
Others			
Japan	70	2	none
TOTALS	------ 63,720	----- 2,895	

where

T = mean maximum air temperature for period considered,
F = total number of ground frosts (grass minimum temperature below 0°C),
S = total number of days with snow cover at 9:00 a.m., and
C = constant such that the climate averaged WI is zero.

Figures 1 through 4 show the index and its parts for Manchester airport in England. It can be seen that four of the past five winters have been warmer than average for the 1961–1990 period.

Figure 5 shows how Manchester's winter index correlates well with estimates of rock salt use in Great Britain during 1975–1991. One might envisage that if RWISs are effective, there should be a detectable shift to the left of this line of best fit. More cold winters are required before any hypothesis can be tested. Figure 6 shows such a shift in the county of Cheshire, England. Salt use is plotted against the Manchester winter index for 5 years before and 5 years after an RWIS

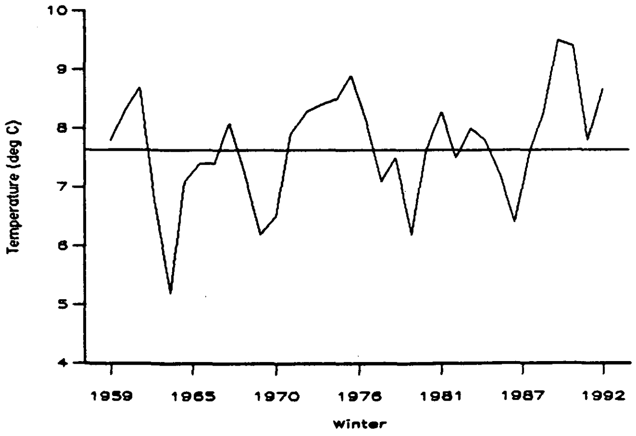

FIGURE 1 Mean maximum temperature, November 1 to March 31, Manchester airport.

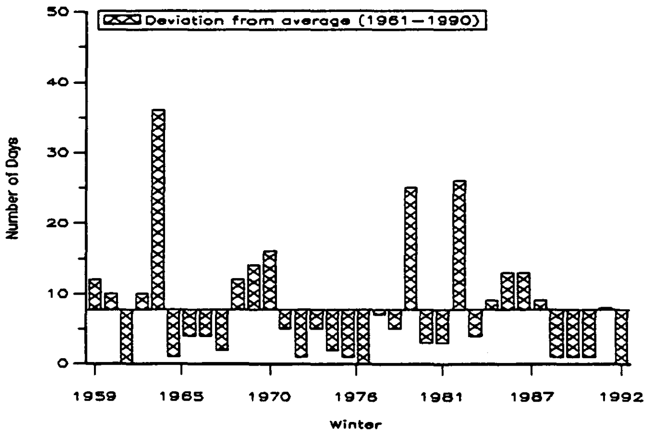

FIGURE 2 Number of days of snow cover at 9:00 a.m., Manchester airport.

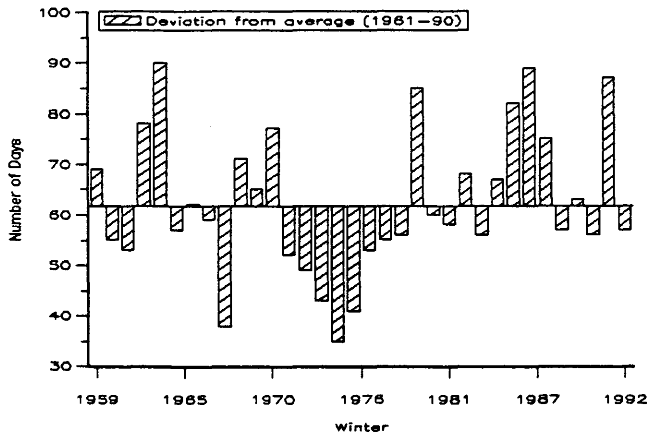

FIGURE 3 Number of ground frosts, Manchester airport.

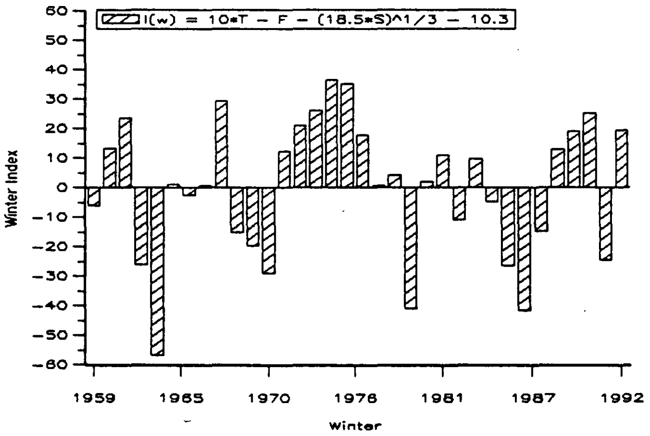

FIGURE 4 Standardized Hulme winter index, Manchester airport.

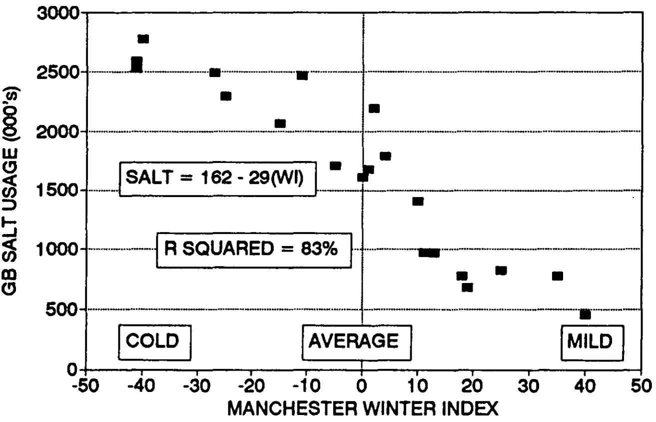

FIGURE 5 Great Britain rock salt use versus Manchester winter index, 1975–1991.

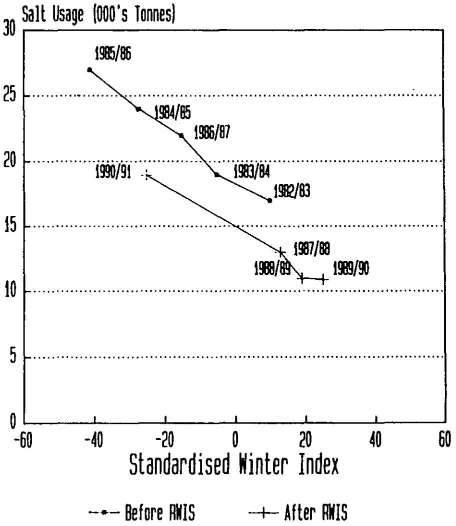

FIGURE 6 Reduction in salt use using RWIS, Cheshire County Council.

was installed. An approximate 20 percent saving in salt use can be seen for a given winter severity (*5*).

SHRP Winter Index

A new winter index has been developed by the University of Birmingham for the SHRP H-207 research program (*2*). It was designed to be a simple objective indication of winter severity with a value ranging from −50 (most severe) through 0 (not too severe and mean level of maintenance) to +50 (warm and no need of maintenance). It has general applicability for other countries. Thus the new winter index is considered to be based on the following parameters for the period from November 1 to March 31:

- Temperature index (TI) is 0 if minimum air temperature is above 0°C, 1 if maximum air temperature is above 0°C and minimum air temperature is at or below 0°C, and 2 if maximum air temperature is at or below 0°C. The average daily value is calculated for the period considered.
- Snowfall (S) is the mean daily value in millimeters.
- Number of air frosts (N) is the mean daily values of number of days with minimum air temperature at or below 0°C ($1 \le N \le 0$).
- Temperature range (R) is the value of mean monthly maximum air temperature minus mean monthly minimum air temperature in degrees Celsius.

These four parameters are summed from daily records and then averaged for each month to eliminate the influence of month length (number of days). The new winter index is thus expressed as

$$\mathrm{WI} = a(\mathrm{TI})^{0.5} + b \ln (S/10 + 1) + c[N/(R + 10)]^{0.5} + d \qquad (2)$$

In Equation 2, the terms including the temperature index and snowfall are expected to make the greatest contribution to the winter index. Temperature range has a similar but inverse distribution to relative humidity (*6*), and in the index it is used as an effective indication of atmospheric humidity. Therefore, the third term in Equation 2 is considered to be an expression of frost likelihood.

There are different ways to determine the coefficients of such a winter index formula. The easiest, most common way is to assign appropriate weights to each term, for example,

1. Term: weight
2. TI: 35 percent
3. Snowfall: 35 percent
4. Frost: 30 percent

The nonequal weight on the third term means that the term is considered to be of slightly less significance to maintenance costs. These weights can be adjusted to suit a particular climate.

The absolute contribution of each term to the winter index is minimum when the temperature index, snowfall, and frost are of minimum value: that is, WI = 50 when TI, S, and N are zero (therefore $d = 50$). It is maximum when the temperature index, snowfall, or frost reaches its maximum. Referring to the U.S. climate data (*5*) and considering potential application of the index in cost analysis, the coefficients of Equation 2 are derived by taking into account the critically significant level of each parameter to winter maintenance cost: WI = −50 when TI = 1.87, $S = 16.5$, $N = 1$, and $R = 1$, solving a set of simple equations such that

$$-50 = -35 - 35 - 30 + 50$$

Thus

$-35 = a(\mathrm{TI})^{0.5}$, so when TI = 1.87, $a = -25.58$;

$-35 = b \ln (S/10 + 1)$, so when $S = 16.5$, $b = -35.68$; and

$-30 = c[N/(R + 10)]^{0.5}$, so when $N = 1$ and $R = 1$, $c = -99.5$.

Equation 2 is therefore written as

$$\mathrm{WI} = -25.58(\mathrm{TI})^{0.5} - 35.68 \ln (S/10 + 1) - 99.5\,[N/(R + 10)]^{0.5} + 50 \qquad (3)$$

Figure 7 shows the spatial distribution of the SHRP index averaged over 1950–1951 to 1985–1986. The index ranges from +40 in Florida, South Texas, and coastal California to −40 in the far Northeast. A full discussion of the spatial and temporal values of the index is given in the SHRP final report (*2*).

If the index is to be of use to road masters, it must be compared with the variation in costs of snow and ice control. Figure 8 shows how cost, in dollars per centerline mile, correlates with the index for each state (data were available for only 40 states). It can be seen that there is an inverse relationship (when cost is logged) and that the state with the highest costs and lowest index is Alaska. Colorado, Minnesota, and Washington have similar costs but very different winter indexes. This difference is due to many factors such as maintenance policy, traffic density, and topography. Population density can be used to explain more of the variance: the roads in a densely populated state have a greater traffic

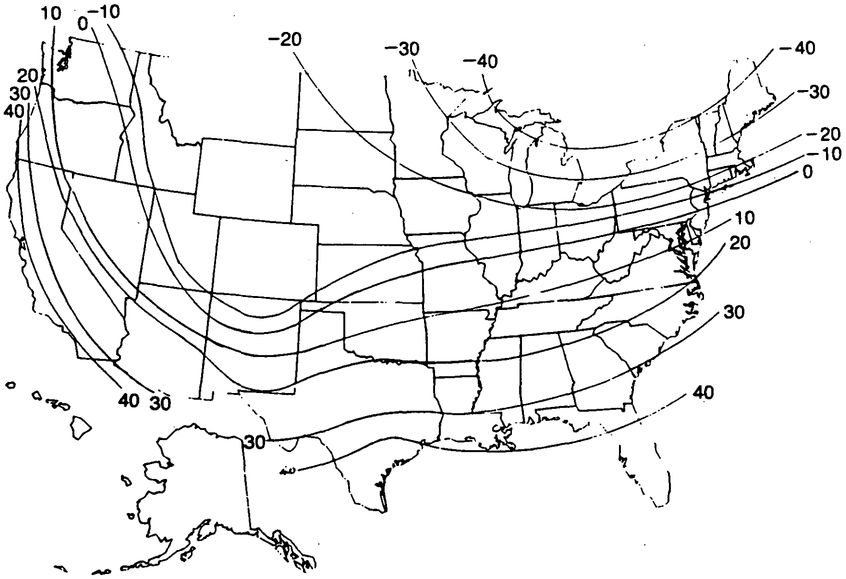

FIGURE 7 Distribution of SHRP winter index across United States, averaged over 1950–1951 to 1985–1986.

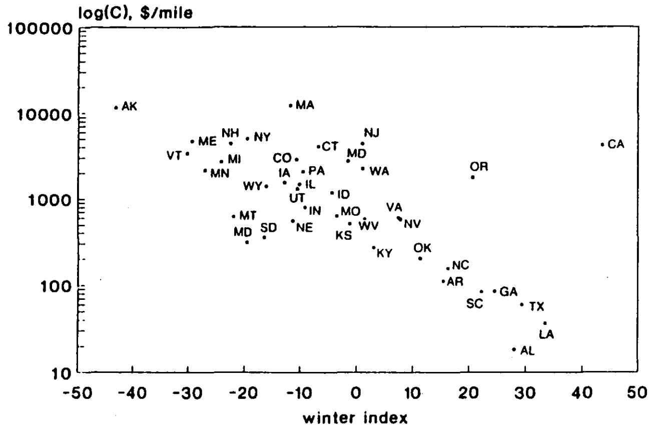

FIGURE 8 Correlation of cost of snow and ice control in each state ($/centerline-mi) with SHRP winter index.

flow and often more priority is given to snow and ice control. Using stepwise regression, the following equation is obtained:

$$C = 632.3 + [7.3 * P * \exp(-0.09 * \mathrm{WI})] - [(0.19 * \mathrm{WI})^3/(1 + P)] \qquad (4)$$

where P is the population density in persons per square kilometer. This equation explains 84 percent of the variation in maintenance costs. Thus if a state is spending significantly more than predicted by Equation 4, cost savings are likely. The winter index could be used to see if the introduction of a RWIS is reducing costs below those predicted by Equation 4.

The winter index can also be used at the district level to monitor costs and salt and sand consumption. For instance, in the metropolitan area of Minnesota near Duluth, the following relationships were found between the winter index and salt and sand use (in tons per lane mile):

$$\mathrm{sand} = 571 + 12 * \mathrm{WI} - 0.347(\mathrm{WI} + 50)^2 \qquad R^2 = .977 \qquad (5)$$

$$\mathrm{salt} = 83 + 1.25 * \mathrm{WI} - 0.054(\mathrm{WI} + 50)^2 \qquad R^2 = .96 \qquad (6)$$

It is too early in the United States to determine if RWISs are having the same impact in reducing the costs of snow and ice control. The SHRP winter index should allow estimates to be made.

COST 309 Winter Index

Denmark has developed a winter index for COST 309 that uses RWIS data at a county level (*1,7*). The index is given as

$$\mathrm{WI} = \text{sum of } W(\text{day}) \text{ from October 15 to April 15}$$

where

$W(\text{day}) = a * (b + c + d + e) + a$;

a = 1, if road temperature is less than 0.5°C at any moment within a 24-hr period; otherwise $a = 0$;

b = number of times road temperature is below 0°C at same time that road temperature is lower than air dewpoint, and this for at least 3 hr within an interval of at least 12 hr; thus maximum value for $b = 2$;

c = number of times road temperature declines below 0°C (from at least 0.5°C to −0.5°C) within a 24-hr period;

d = 1, if snowfall of at least 1 cm is reported within a 24-hr period; otherwise $d = 0$; and

e = if noteworthy snowdrift has occurred; otherwise $e = 0$.

The values for a, b, and c are averaged from the total number of RWIS outstations in a county. The index is then compared to what they have described as an activity level, which is defined as

$$\text{activity level} = N1 + N2$$

where $N1$ is the number of routes salted divided by the number of routes and $N2$ is the number of snow routes cleared divided by the number of snow routes.

The study shows a clear linear relationship between salt use for the whole of Denmark and the winter index averaged for all counties over three winters (*1*). The ratio of winter activity to winter index for each county is calculated, and the lower the ratio, the more efficient the county must be. In 1989–1990, 8 of the 11 counties were very similar with a ratio near 0.5, whereas 3 of the counties had ratios of less than 0.4.

CONCLUSIONS

The Danish index must be calculated in real time on a daily basis. The full index could not be calculated automatically by the RWIS, but some of the elements (a, b, c, and d) could be stored for the road master to make the calculation easier. Elements e, $N1$, and $N2$ would have to be entered by the road master. This daily interaction with the RWIS to summarize the day's activities is to be encouraged, and software could easily be designed to make the task as simple as possible and to display the results for the winter so far. Unfortunately, using actual road-surface temperatures means that the current winter cannot be compared easily with winters before the RWIS was installed.

Therefore, to assess the impact of the RWIS on the costs of snow and ice control, an index based on air temperatures is required. Once an RWIS has been installed, however, another winter index based on road temperatures could be calculated alongside the first index to assess efficiency spatially across a region.

It is important to archive the RWIS data and activity data if the efficiency of snow and ice control is to be properly assessed. Better software is required within the RWIS to make this task easier. For now road masters must judge which is the best winter index for their own circumstances and archive the required information themselves.

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