# Theoretical Background for Use of a Road Weather Information System

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Background factors must be considered in the adaptation of a road weather information system for a maintenance area. These factors may be climatological, meteorological, or related to the structure of the road infrastructure. The methodology used in Sweden involves analyses of thermal mapping along the actual road stretches, climatological statistics such as precipitation patterns and average temperature, and so forth. Other important components are the variation in topography and vegetation. These factors are integrated into a decision procedure for which the output is a proper location based on climatology of the field stations within the system.

The possibility of maintaining a high and effective level of winter road maintenance has increased dramatically through the use of road weather information systems (RWISs). Records of climatological parameters such as air temperature, air humidity, precipitation, and wind, together with pavement temperature, make it possible to detect risk of icy conditions in an early stage and to take action against them. However, to gain optimum benefits from this type of automatic system, several background factors must be considered during the planning and establishment of a system in a new area. Accuracy and reliability are to a great extent determined by the capabilities and accuracy of the specific sensors, but without knowledge of the local and microclimatological situation information provided by the sensors will be misleading and difficult to interpret. The topoclimatological conditions are also very important when the RWIS is used along with tools such as forecast models, stretchwise information, and winter indexes (*1*). An overview of the climatological background that must be considered in the establishment of an RWIS is presented here.

The road surface temperature (RST) is determined by several factors. To an extent determined by the prevailing weather, the local topography causes a more or less pronounced effect on the temperature pattern, along with factors such as altitude and surface construction. In the analysis of the climatology of a certain area or region and its need for field stations, it is important to consider local and regional temperature differences. Locally induced temperature variations are best detected and studied by direct measurements, that is, thermal mapping. Temperature variations on the regional scale are determined by analysis of synoptic weather data and topographical maps. These analyses form the basis for determining the most appropriate locations of field stations in an RWIS.

## Topoclimatology

The combination of a varied topography and variations in the weather in a landscape causes a diversified temperature distribution that has great impact on the risk of winter slipperiness. The main topographical factors controlling temperature variations are valleys, elevated areas, and screened areas. Bridges, road materials, and vegetation are also factors that alone or in combination with the topoclimate must be regarded for analyses of the temperature variations.

### Valleys

Accumulation of cold air in valleys during clear, calm nights results in a varying air temperature pattern along road stretches. Bogren and Gustavsson (2) demonstrated that the variation in temperature between valley bottoms and summits can be related to such factors as the valley geometry, that is, the width and depth of the valley. Another factor of great importance is the wind exposure of the valleys. The return period of the occurrence of the cold air pool, as well as the magnitude of the temperature difference, increased if the valley location was sheltered from the wind by, for example, trees. Pooling of cold air in valleys causes a reduction of the RST compared to that of nearby neutral areas. As shown by Gustavsson (*3*) and Bogren and Gustavsson (*2*), the lowering of the RST is linearly related to the lowering of the air temperature, which is termed the intensity of the pooling of cold air. An air temperature difference of 6°C results in a lowering of the RST by approximately 2.5°C. By use of the relationship between the geometric factors and variation in air temperature, it is possible to calculate the variation in RST.

## Elevated Areas

The local topography has a small effect on temperature variations during cloudy, windy weather. Counterradiation from clouds and turbulence caused by wind reduce local temperature variations, which otherwise develop under more stable conditions. Under cloudy, windy conditions variations in temperature are largely caused by changes in altitude, and the influence of local topography is most reduced. Under fully mixed conditions the temperature falls by approximately 1°C per 100 m. This general tendency can be applied to both night and day.

## Screening

The effect of screening as a factor causing large RST variations is connected to clear day conditions. The largest influence of screening, which can affect the risk of slipperiness, occurs during late autumn and early spring. A study by Bogren (*4*) demonstrated that the factors of greatest importance to screening effects are the position of the sun in relation to the site (time of day and season) and the type of screening object and its orientation in relation to the road. The intensity of the temperature difference that develops between the screened and exposed sites is also affected by the amount of cloud cover. That the orientation and geometrical configuration of the screening object are the most important factors controlling the variation in surface temperature during days with sunshine has also been documented in a study by Gustavsson and Bogren (*5*). Figure 1 shows the temperature pattern of the RST during a clear day in February. It is obvious how distinctly and regularly the RST reacts on the screening objects along the road stretch.

## Bridges

Analyses of bridges is important because they often have a different temperature development than adjacent roads, caused by different qualities of heat storage and conductance. The importance of these temperature differences is most pronounced during changes in the weather during both cooling and warming trends. Factors controlling the surface temperature of bridges include the type of bridge

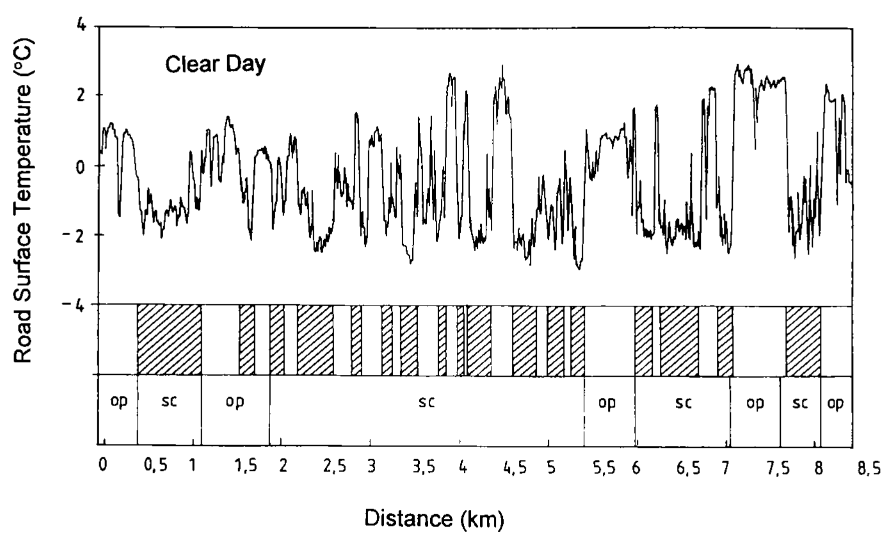


**FIGURE 1 Thermal mapping showing effect of screening objects (gray) on road surface temperature on clear day (op—open, well-exposed; sc—screened).**

crossing (over water or other roads), bridge composition, bridge thickness, and weather. Another factor that can affect the temperature pattern at bridges is the surrounding terrain characteristics. In analysis of climate and topoclimatological characteristics in an area, regional climate must be considered. When large areas with variations in latitudes and altitudes are analyzed, factors such as distance to the sea or to large lakes must be considered along with spatial differences in the distribution of precipitation. The variation in regional climate must be considered in all types of weather because these differences could be of the same magnitude as the variations caused by topoclimatological factors.

## Thermal Mapping

Temperature variations within a small area are the result of several factors. By use of the thermal mapping technique, the total result of these factors is detected as the temperature variation. When these measurements are combined with field analyses of topography and weather parameters, the relative importance of the different factors can be determined.

Studies of thermal mappings and climatological records from field stations within the RWIS has made it possible to evaluate the effect of different terrain factors on the temperature pattern. The factors that must be covered and analyzed to determine the locations of road weather sensors are radiation, advection, and construction of the road.

### Radiation

Heating and cooling rates of the road surface are largely determined by radiative processes. During the day incoming solar radiation heats exposed areas while screened areas are shaded, creating large temperature variations within a short distance. A clear sky allows solar radiation to heat the road during the day. Solar radiation is disturbed by road rock cuts and vegetation, which form shadow patterns on the road.

It is possible to consider the potential for radiative input and screening by combining the thermal maps with a study of the field conditions along the roads where the potential for screening can be determined. The relative input of radiative cooling can be determined. This can be done by use of video recording through which the sky view is calculated according to the degree of obstruction of the sky. It is also possible to use a radiometer for direct measurements of the radiation conditions. A mobile-mounted radiometer can also be used for the stretches of road. Information from nearby field stations may also be used in the investigation of a new area.

### Advection

The horizontal transport of air from nearby areas has a marked effect on RST. Air transported from an adjacent area may have properties that differ from those of the road. A typical example occurs when cool air produced on an open area is drained from its production area toward the lower-lying road. The wind may also play a significant role in bringing air with different properties, such as temperature and humidity, over the road.

The advective factor is registered by measuring the air temperature at two levels. By performing thermal mapping along the same route at different times, it is possible to analyze the relative change in temperature during a period, revealing the relative importance of the advective term. Moisture from adjacent lakes or other wet areas can also play an important role in affecting the risk of slipperiness on the roads. During midwinter, when the lakes and bogs are ground frozen, these areas may produce very cold air that can be advected to the road.

### Construction of Roads

Differences in road construction materials and types of surface coating will provide variations in thermal properties. Surface temperature measurements made with infrared recording equipment take these factors into account. To take the thermal properties into account, thermal mapping may be performed in two ways. One method is to make the measurements after midnight, to allow the minimum temperature to be reached. Another method is to perform two measurements along the same route at different times so that the differences in cooling rates at different locations may be analyzed. To cover the different components that give rise to temperature variations and risk of slipperiness, thermal mapping is performed under various weather conditions, including cloudiness, wind, and time of day or night.

Clear situations are divided into day and night situations. Nocturnal thermal mapping missions should be performed during calm weather conditions because the goal is to detect the temperature pattern created by the gathering of cold air and radiative loss. Thermal mapping carried out during the day is performed to detect the temperature anomalies associated with screening from topography and vegetation. These measurements are not dependent on wind conditions.

Cloudy conditions are divided into partly cloudy and overcast situations. For cloudy conditions the best results are achieved when there is a prevailing wind. The measurements can be carried out independently of the time of day.

## SITING OF FIELD STATIONS

To site the field stations in the most appropriate locations a thorough climatological analysis must be carried out. The fundamental tool for achieving knowledge of the climatological variability within an area is a thermal mapping. The field stations should be located at road sites that are frequently struck by slipperiness and where an early warning is given during different weather conditions. Typical locations are valleys, high areas, bridges, and road rock cuts. At the field stations air temperature and humidity are traditionally measured at the 2-m height and the RST is measured by pavement sensors in the top layer of the road coating. Several of the stations have extra equipment, such as sensors for wind speed, wind direction, and precipitation.

Research has shown that the specific location of the sensors at each station is important for the timing of ice detection. Because of local factors the development of the internal boundary layer influences the temperature stratification at a site. This indicates that air temperature and humidity sensors should be located according to site-specific conditions. Future research will show if various levels must be used or if a software transformation can be used.

Interpretation of the temperature recordings from a certain site requires awareness of the RST variations that can occur in different lanes or at different locations within the lane. Such differences may occur because of differences in traffic density or various surface coatings.

It is also important to be aware that sensors for measuring precipitation and wind are very sensitive to obstruction. A major mistake is to underestimate the impact of vegetation or other objects, which may disturb the recording and give false information about the risk of slipperiness.

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