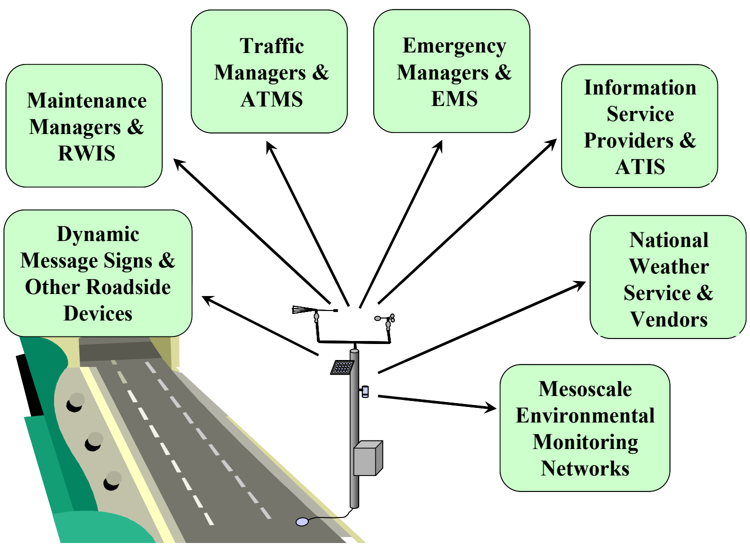
Environmental Sensor Technologies

This section presents an overview of environmental sensor technologies including fixed environmental sensor stations (ESS), mobile sensing devices, and remote sensing systems. The conclusion summarizes weather impacts on roads, traffic, and operational decisions and discusses implementation issues associated with ESS, such as data sharing and institutional coordination.

Transportation managers must access data on environmental conditions to effectively and efficiently mitigate weather impacts on traffic operations. This data serves as decision support to managers, who disseminate relevant road weather information to the public. There are many operational applications for environmental data. Environmental data may be integrated into automated motorist warning systems, road weather information systems (RWIS), advanced traffic management systems (ATMS), emergency management systems (EMS), and advanced traveler information systems (ATIS). This information may also be used to enhance forecasts and supplement mesoscale environmental monitoring networks (i.e., mesonets).

Winter maintenance managers utilize road weather information to assess the nature and magnitude of threats, make staffing decisions, plan treatment strategies, minimize costs (i.e., labor, equipment, materials), and assess the effectiveness of treatment activities (by agency staff or subcontractors). Traffic managers may access road weather data to control traffic flow and warn motorists. Based upon prevailing or predicted conditions, managers may alter traffic signal timing parameters, modify incident detection algorithms, vary speed limits, and restrict access to designated routes, lanes or vehicle types (e.g., tractor-trailers). Some Traffic Management Centers utilize ATMS that integrate weather data with traffic monitoring and control software. Emergency managers may employ decision support systems that integrate weather observations and forecasts with population data, topographic data, as well as road network and traffic data. When faced with flooding, tornadoes, hurricanes, or wild fires; emergency managers may use this data to evacuate vulnerable residents, close threatened roadways and bridges, and disseminate information to the public.



ESS Operational Applications

Transportation managers disseminate road weather information to motorists in order to influence their travel decisions. This allows travelers to make choices about travel mode, departure time, route selection, vehicle type and equipment, and driving behavior. Road weather advisories and regulations may be furnished via roadway warning systems, interactive telephone systems, web sites, kiosks, and media broadcasts.

Environmental Sensor Stations (ESS)

An ESS is a fixed roadway location with one or more sensors measuring atmospheric, surface (i.e., pavement and soil), and/or hydrologic (i.e., water level) conditions. These stations are typically deployed as field components of RWIS. Data collected from environmental sensors in the field are stored onsite in a Remote Processing Unit (RPU) located in a cabinet. In addition to the RPU, cabinets typically house power supply and battery back-up devices. The RPU transmits environmental data to a central location via a communication system. Central RWIS hardware and software collect field data from numerous ESS, process data to support various operational applications, and display or disseminate road weather data in a format that can be easily interpreted by a user.

Atmospheric Sensors
Atmospheric sensors measure various weather conditions including air temperature, barometric pressure, relative humidity, wind speed and direction, precipitation, visibility distance, and cloud cover (an indication of solar radiation). Air temperature can be measured with liquid, gas or electrical thermometers. Electrical thermometers, which are normally used in automated sensor stations, contain metal wires that exhibit increased resistance to electrical current as the temperature rises. Platinum and copper are commonly utilized due to a nearly linear relationship between resistance of these materials and temperature. Electrical thermometers, also known as resistance thermometers and thermoelectric thermometers, provide accurate readings over a wide range of temperatures.

Mercury and aneroid barometers are employed to detect atmospheric pressure or the pressure due to the force of gravity on air molecules in a column of air. Because they are more accurate than mercury barometers, aneroid barometers are typically used in meteorological applications. An aneroid barometer contains an aneroid cell—a sealed, flexible metal box or pair of thin circular disks—that expands or contracts as atmospheric pressure changes.

Relative humidity—a measure of air's water vapor content—can be measured by three types of hygrometers. Dew-point, capacitor, and electrical hygrometers detect humidity by sensing changes in a substance caused by moisture. A dew-point hygrometer ascertains humidity by cooling a mirror until condensation forms. The temperature at which condensation forms can be used to calculate humidity, given the prevailing temperature and pressure. Capacitor hygrometers measure the capacitance of a material, such as polymer film, which varies as humidity changes. Electrical hygrometers accurately detect resistance to electrical current in a material, which changes with humidity. These devices typically contain a carbon-coated plastic strip that absorbs moisture from the air. As humidity rises or falls, changes in the resistance of the carbon coating can be ascertained.

Wind vanes are employed to determine the direction from which wind is blowing. A conventional wind vane indicates wind direction with a tail fin mounted on a horizontal shaft that is attached to a vertical axis. The tail causes the wind vane to rotate in the horizontal plane. Wind speed is typically measured by anemometers with propellers or cups. A vane-oriented propeller anemometer uses two to four blades, which rotate about a horizontal shaft, and a vane attached to the shaft to indicate direction.

Wind Vane

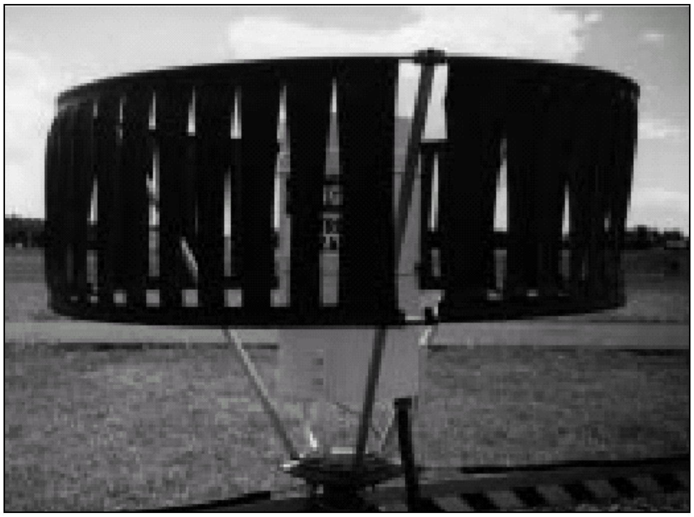
Propeller Anemometer

Rotating cup anemometers have three to six hemispherical cups that revolve around a vertical axis, as depicted below. Speed is calculated based upon the rotation rate of propeller blades or cups. Wind speed can also be determined with non-mechanical sensors, such as hot wire and sonic anemometers. Hot wire anemometers ascertain the degree of cooling of a heated metal wire, which is a function of air speed. A sonic anemometer gauges wind speeds based upon properties of wind-borne sound waves.

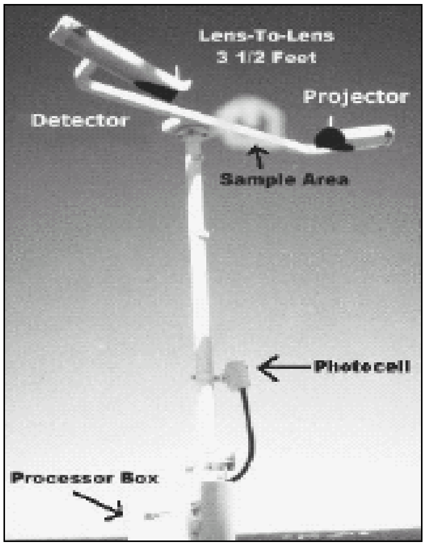
Precipitation measurements are made with rain gauges that sense precipitation type, measure the amount and rate of rainfall (or the liquid equivalent of snow or sleet), as well as determine the start and end times of a precipitation event. Tipping bucket rain gauges and weighing rain gauges are commonly used in ESS. In tipping bucket gauges, a cylinder collects and funnels rainfall into a small bucket that holds 0.01 inches (0.30 mm) of water. In climates with frequent snowfall, the bucket is heated and equipped with a wind shield. When it is full, the bucket tips and empties the water while another bucket is lifted into position under the funnel. Every time a bucket tips an electrical contact is closed sending a signal to a recorder. Weighing rain gauges are capable of measuring all types of precipitation without heaters. Precipitation is funneled into a bucket that is weighted to assess amounts. These gauges require more maintenance than tipping bucket gauges. Float-type rain gauges use a float on the water surface to measure the amount liquid precipitation. Rain-intensity gauges or rate-of-rainfall gauges measure the instantaneous rate at which rain falls onto a surface.


Cup Anemometer


Sonic Anemometer


Heated Tipping Bucket Rain Gauge

Visibility can be reduced by various weather phenomena including fog, heavy precipitation, drifting snow, and wind-blown dust. Visibility distance can be measured directly with sensors or remotely via Closed Circuit Television (CCTV) cameras. Objects suspended in the air—such as minute water droplets forming fog—scatter energy. Visibility sensors detect the amount of scattered light to compute visibility distances. As shown in the figure, a forward-scatter visibility sensor has a projector that emits a pulsed flash of light in a cone-shaped beam. A detector is positioned 33 to 70 degrees from the projector axis, such that the beam does not fall directly on the detector lens. Thus, the detector senses only the light scattered by fog or dust. Backward-scatter visibility sensors have aligned projectors and detectors and operate in a manner similar to forward-scatter sensors. Visibility distance can also be discerned by aiming a CCTV camera at objects at known distances, such as roadside signs with flashing beacons.



Forward-Scatter Visibility Sensor

Surface Sensors

Surface sensors measure pavement conditions (e.g., temperature, dry, wet, ice, freeze point, chemical concentration), and subsurface or soil conditions. There are two basic types of surface sensors; active and passive. Active sensors generate and emit a signal and measure the radiation reflected by a targeted surface. Passive sensors detect energy radiating from an external source. Passive pavement temperature sensors are normally buried in the road surface. These sensors are designed with thermal properties similar to pavement so that they are heated and cooled at the same rate.

Pavement condition can be monitored with sensors embedded in road surfaces, friction measuring devices, cameras, and microphones. Embedded sensors typically distinguish between two or three pavement states (e.g., dry or wet). The surface of an active pavement condition sensor is cooled below ambient air temperature. If pavement moisture is present, dew or frost will form on the cooled surface. This type of sensor can also be used to assess the effectiveness of road treatment chemicals and determine the temperature at which pavement moisture will freeze. Another type of pavement condition sensor emits microwaves from an overhead transmitter. If moisture is present on the pavement, microwaves reflect off of the water surface and the road surface. A receiver detects the pattern created by the reflections to compute the thickness and salinity of a film of water.


Pavement Sensor

Friction measurement devices assess the pavement coefficient and classify conditions based upon assigned ranges of values. Video signals from CCTV cameras and audio signals recorded by microphones can also be analyzed to distinguish differences in pavement appearance or tire sounds caused by water, snow, or ice. Subsurface conditions (e.g., soil temperature, soil moisture, freeze/thaw cycles) may be detected with a soil thermometer or geothermometer, which measures values at various depths. These conditions characterize the transfer of heat between the soil and the pavement.

<u>Hydrologic Sensors</u>

Various hydrologic sensors detect water levels in streams and rivers, and tide levels to assess flood and storm surge hazards. Ultrasonic water level sensors make use of acoustics or sound waves to measure the distance from a transducer to the water surface. Stilling wells contain float sensors to measure water levels. The float is typically enclosed in a pipe or cylinder, which protects the sensor and allows the free movement of water. Tide gauges may be used to measure storm surge caused by a tropical storm. These gauges operate in a manner similar to stilling wells to measure the height of tide.

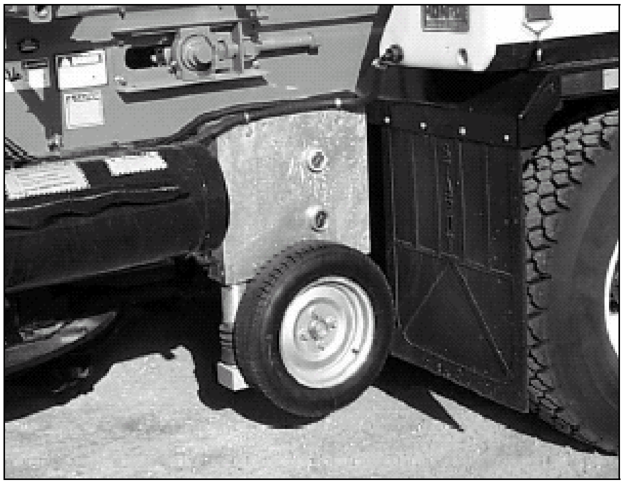
Stilling Well

Mobile Sensing

Mobile sensing involves the integration of environmental sensors with vehicle systems. In combination with global positioning system (GPS) technologies, truck-mounted sensor systems can be utilized to sense pavement conditions (e.g., temperature, friction) and atmospheric conditions (e.g., air temperature). Transportation agencies in Iowa, Michigan and Minnesota have partnered to deploy and evaluate advanced maintenance vehicles equipped with mobile sensors.

Pavement friction coefficient can be assessed with deceleration devices, locked wheels, and variable slip systems. Deceleration devices measure a signal generated by a strain gauge when a vehicle brakes. The signal, which is proportional to the deceleration rate, is used to compute the friction coefficient. Friction can also be determined by a locked wheel that is towed behind a vehicle traveling at 30 to 40 mph (49 to 64 kph). Brakes are applied to lock the wheel for one second while the resistive drag force is measured. Variable slip systems calculate pavement friction as a function of the degree of slip between a tire and the road. A friction meter being tested by the partners is shown in the figure below.

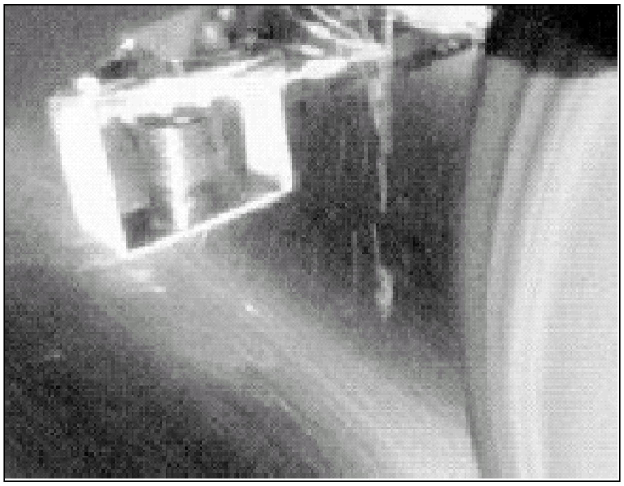
The friction meter is mounted on the frame of a maintenance vehicle and contains a variable slip wheel with an electric brake. The wheel speed is measured as the brake is applied and released by a computerized control system. This rotational speed is used to calculate torque, which is converted into a friction coefficient value. The control system displays friction levels to the driver in five color-coded categories (i.e., “Hazardous,” “Very Slippery,” “Slippery,” “Acceptable,” and “Good”).



Friction Meter Mounted on Snowplow

The automotive industry has introduced traction control systems and anti-lock braking systems that can also be employed for mobile pavement friction measurement. Traction control systems can detect traction of vehicle wheels as they rotate. While, anti-lock braking systems only operate during braking, resulting in fewer measurements.

Agencies in Iowa, Michigan and Minnesota are also evaluating mobile sensors to determine pavement freeze point temperature. The freeze point sensor is composed of a receptacle that collects liquid from tire spray, as shown in the figure. A computer system closes the receptacle lid, calculates the freeze point of the liquid, and blows air over the sensor to prepare for the next measurement cycle. Additional research is needed due to the complexities of mobile pavement condition sensing. Researchers in the U.S., Europe, and Japan are currently prototyping and evaluating various devices that ascertain pavement conditions.



Freeze Point Temperature Sensor

Remote Sensing

In remote sensing, a detector is located at a significant distance from a target. The sensor is typically part of a radar or satellite system used for surveillance of meteorological and oceanographic conditions. Images and observations from remote sensors are used for weather monitoring and forecasting from local to global scales. Remote sensing is used for quantitatively measuring atmospheric temperature and wind patterns, monitoring advancing fronts and storms (e.g., hurricanes, blizzards), imaging of water (i.e., oceans, lakes, rivers, soil moisture, vapor in the air, clouds, snow cover), as well as estimating runoff and flood potential from thawing.

Water in its gaseous state (or water vapor) is essential in the development and propagation of weather. Water vapor has historically been a poorly characterized meteorological variable because its distribution fluctuates widely (both spatially and temporally) and it is difficult to measure using traditional atmospheric observing systems. The Federal Highway Administration (FHWA) has collaborated with the National Oceanic and Atmospheric Administration (NOAA), the National Geodetic Survey/Continuously Operating Reference Station (NGS/CORS), and the Coast Guard to develop a Nationwide Differential Global Positioning System (NDGPS) capable of observing precipitable water vapor.

The NDGPS is comprised of systems that measure satellite signal delays caused by atmospheric vapor. Twenty-four GPS satellites in Earth's orbit emit radio signals to ground instruments, which accurately compute precipitable water vapor data every 30 minutes. NDGPS is more precise than the civilian GPS system, known as the standard positioning service, providing three-foot (one-meter) accuracy. This high accuracy is expected to improve to 0.8 to 8.0 inches (2 to 20 centimeters) in the near future. The NDGPS data—available on the project web site, *www.gpsmet.noaa.gov/jsp/index.jsp*—has been used to improve the accuracy of short-term, precipitation forecasts disseminated by the National Weather Service (NWS).

Conclusion

Weather acts through visibility impairments, precipitation, high winds, and temperature extremes to affect driver capabilities, vehicle performance (i.e., traction, stability and maneuverability), pavement friction, and roadway infrastructure. Fixed ESS, mobile sensors, and remote sensing systems can provide valuable data that can be used to improve roadway safety, maintain roadway mobility, enhance agency productivity, and facilitate dissemination of traveler information to the public. The following table summarizes the impacts of various weather events on roadways, traffic flow, and operational decisions.

Weather Impacts on Roads, Traffic and Operational Decisions

Road Weather Variables	Roadway Impacts	Traffic Flow Impacts	Operational Impacts
Air temperature and humidity	N/A	N/A	• Road treatment strategy (e.g., snow and ice control)
Wind speed	• Visibility distance (due to blowing snow, dust) • Lane obstruction (due to wind-blown snow, debris)	• Traffic speed • Travel time delay • Accident risk	• Vehicle performance (e.g., stability) • Access control (e.g., restrict vehicle type, close road) • Evacuation decision support
Precipitation (type, rate, start/end times)	• Visibility distance • Pavement friction • Lane obstruction	• Roadway capacity • Traffic speed • Travel time delay • Accident risk	• Vehicle performance (e.g., traction) • Driver capabilities/behavior • Road treatment strategy • Traffic signal timing • Speed limit control • Evacuation decision support • Institutional coordination
Fog	• Visibility distance	• Traffic speed • Speed variance • Travel time delay • Accident risk	• Driver capabilities/behavior • Road treatment strategy • Access control • Speed limit control
Pavement temperature	• Infrastructure damage	N/A	• Road treatment strategy
Pavement condition	• Pavement friction • Infrastructure damage	• Roadway capacity • Traffic speed • Travel time delay • Accident risk	• Vehicle performance • Driver capabilities/behavior (e.g., route choice) • Road treatment strategy • Traffic signal timing • Speed limit control
Water level	• Lane submersion	• Traffic speed • Travel time delay • Accident risk	• Access control • Evacuation decision support • Institutional coordination

Several issues must be considered when planning to deploy ESS and implement RWIS. Concerns include procurement and maintenance, data sharing, and institutional issues. Partnerships with neighboring public agencies and the private sector can facilitate data sharing and help defray the initial and recurring costs of field sensors, communications infrastructure, central hardware, and processing software. Another alternative is to fund RWIS component installation as part of larger construction or Intelligent Transportation Systems (ITS) projects. Preventive maintenance funds must also be secured to ensure that sensors are properly calibrated and provide accurate data.

Exchanging environmental data and information with other agencies can minimize surveillance costs. Environmental monitoring networks can be created to collect and integrate data from many sources, store relevant data in centralized databases, and disseminate information in useful formats. Potential data sources include surface weather observation systems deployed by the NWS, the Federal Aviation Administration, the U.S. Geological Survey, the Department of Agriculture, the Forest Service, and the Environmental Protection Agency. The need for redundant infrastructure can be eliminated by coordinating with other agencies.

Because environmental sensors are available from various vendors in numerous configurations, technological compatibility and communications standards must be considered in joint efforts. The U.S. DOT promotes interoperable systems through the ITS Standards Program, which develops standards detailing how various systems are interconnected within the framework of the National ITS Architecture. The National Transportation Communications for ITS Protocol (NTCIP) is a set of standards that facilitate interoperability of roadside devices made by different vendors. The NTCIP includes object definitions for ESS, which were initially published in October 1998 and amended in January 2001. The object definitions document (i.e., NTCIP 1204)—which describes data collected from weather, pavement, and air quality sensors—can be used to integrate disparate field devices into a central system with common data sets and communications protocols. Release of version two of the ESS object definitions document is expected in June 2004.

In 2005, another document (i.e., NTCIP 1301) describing message sets for disseminating road weather information to managers and travelers will be released. The NTCIP ESS standard has been successfully tested in Minnesota and Washington State. Additional information about ESS standards can be found on the ITS Standards Program web site (*www.its-standards.net/Documents/ess_advisory.htm*) and the Road Weather Management Program web site (*ops.fhwa.dot.gov/weather/publications/ rwis_brochure.pdf*).

Another major institutional issue is system acceptance. Potential benefits from ESS and RWIS deployments will not be realized if transportation managers do not use them. The organizational culture, decision-making processes, and technical capabilities of users must be carefully considered during design and implementation. All users desire “timely, relevant, accurate” road weather information. However, these criteria may be defined differently depending on the operational application. For example, a maintenance manager may consider a 24-hour precipitation forecast “timely” for treatment strategy planning, while a traffic manager needs real-time snow accumulation data to adjust traffic signal timing parameters. “Relevant” environmental data is presented to the user in a format that is easily interpreted and suitable for decision support. Software programs must be developed to customize raw data (such as soil temperature) into useful information (such as a pavement temperature forecast based upon air and soil temperatures). Managers have various technological options depending on their weather information needs, operational procedures, and mitigation strategies.

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