Chapter 6

GUIDELINES FOR RWIS EQUIPMENT

This chapter summarizes NTCIP standards and meteorological guidelines that are available to guide future development of RWIS.

NTCIP Standards

The National Transportation Communications for ITS Protocol (NTCIP) specifies guidelines for achieving and enhancing interchangeability and interoperability of various components of transportation systems by making system upgrades and expansions easier to implement and more cost-effective. Historically, there have been numerous networking problems associated with deployment of ITS systems largely because of a lack of communication standards insuring device and software portability. As a result, NTCIP is now being widely accepted and embraced in the procurement, deployment and maintenance process for RWIS devices and various other specific transportation communications systems. [6]

Within the NTCIP umbrella, interchangeability refers to the ability to exchange devices of the same type from different vendors without needing to update the software or related systems (e.g., temperature probes from two separate venders). Interoperability refers to the ability to operate devices from different vendors or of different types on the same communication channel (e.g., closed circuit television cameras and environmental sensors).

Development and maintenance of NTCIP is undertaken by:

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What is NTCIP in a nutshell?

The NTCIP guidelines are a collection of communication protocols and data definitions that address communication modes between various subsystems of the ITS National Architecture. Applications for NTCIP are generally intended to handle needs in two areas, center-to-center and center-to-field. The former usually involves computer-to-computer interaction where the communicating computers may be in the same room or associated with an external agency immediately adjacent or across the country. Center-to-field refers to a field device located roadside or on a vehicle that communicates with a central computer. The central computer may be located at a management center or remotely located. [6]

Examples of NTCIP center-to-center protocols are traveler subsystems (e.g., remote traveler support and all modes of traveler information) and center subsystems (e.g., transit management and emergency management). Examples of NTCIP center-to-field protocols are vehicle subsystems (e.g., transit, commercial and emergency) and wayside subsystems (e.g., environmental sensors and traffic signals).

What about existing standards from the Internet Community? Can they be used? Why are more needed?

Since the advent of the computer and increased popularity of the Internet there have been numerous established and accepted protocols that define data structure and communication procedures between electronic devices, (e.g., The Open Systems Interconnect seven-layer reference model (OSI) which was established by the International Standards Organization (ISO) and other standards making organizations for the telecommunications industry). As is the case in the telecommunications community, the transportation industry faces many specific and unique standardization requirements within the National ITS Architecture (primarily device capability issues) in order to assist in efficient deployment, expansion, maintenance and operation of its systems. As a result, the intent of NTCIP was to establish understandable communication procedures and device interface guidelines that were directly applicable and unique to the transportation industry. This was accomplished by extending beyond the OSI seven-layer framework through establishing a suite of communication standards regarding informational data and device interface requirements.

Many procedures and rules parallel OSI protocols. To take advantage of the overlap, NTCIP extensively employs and builds upon OSI standards within the suite of NTCIP standards where possible, since there are some obvious benefits in doing so, as professed by AASHTO, ITE and NEMA. These include [7]:

- reuse of software modules during development
- faster implementation
- reducing risk
- ability to integrate components from different manufacturers
- unambiguous meanings of terminology
- building on proven technologies

What are the Benefits of NTCIP Compliant Systems?

NTCIP has many future benefits to the transportation community at large. In addition, agencies that begin to move toward compliancy can experience such benefits as:

- **Avoiding early obsolescence** of software/hardware. This insures that current NTCIP compliant equipment remains operable and compatible in the future.

- **Wider choice of vendors**. Equipment and software to be procured is interchangeable and interoperable with other NTCIP compliant systems.

- **Interagency coordination** will be possible through easy sharing of information (with permission) between agencies. This will facilitate monitoring of conditions in the partnering agencies and implementation of coordinated responses to incidents or changing situations.

- **Use of one communication network for all purposes**. Management will have the flexibility to communicate with a mixture of devices on the same channel. [6]

How do you know if a system is NTCIP compliant?

Roadside systems that are NTCIP compliant are authorized to use the title of Environmental Sensor Station (ESS). Agencies working toward compliance can use outside consultants and testing procedures to determine their progress.

Why wouldn't an agency want their systems to be compliant?

There are several reasons why an agency may not be moving toward compliancy with NTCIP standards, including:

- Lack of information regarding the benefits
- Insufficient resources (financial, labor, etc.) to purchase new systems or retrofit existing systems all at once
- New, compliant systems are available, but unable to communicate with an agency's existing information technology infrastructure

In addition, there are external factors that affect the speed at which transportation agencies can move toward compliancy:

- Definition of "compliant": Does compliancy mean that 100% of agency's systems are fully compliant, or does it mean that an agency is purchasing new systems that are compliant?
- Vendor products: Agency compliance will depend on the ability to obtain compliant products and systems from vendors.
- Standards: Established standards are still limited; many new standards are still in the development process.
- Contract requirements: Compliancy will increase more quickly to the extent that it is required as part of procurement contracts.

A little on NTCIP Structure

Please note: The following is briefly summarized from the NTCIP Guide to provide a cursory understanding to the reader of the NTCIP architecture. For readers requiring more detail regarding NTCIP structure and compliancy concerns please refer to NTCIP 9001 v02.06 (Draft) and other NTCIP standards documents.

The communication standards in NTCIP use a layered structure similar to the schemes implemented by the Internet Engineering Task Force (IETF) and the International Standards Organization (ISO). As a result, the NTCIP naming structure is grouped by the primary mode of application of the standard, referred to as "levels" to help distinguish NTCIP from the IETF and ISO standards. NTCIP is divided into five levels [6]:

Information Level

This level deals with protocol identifying the meaning (objects, conformance groups and message sets) of information data being used in ITS applications. The rules and procedures that make up the protocols of the information level are unique to the transportation industry. As a result, a considerable amount of the development work by NTCIP has focused on identifying necessary data elements and assemblage of those elements into standard objects and message sets for various domains and functions within ITS.

Defined in the standards documents of this level are the object syntax (data structure), access (read-write-execute privileges), status (in development, being phased-out, obsolete or in favor) and description (defines the proper use/purpose of the objects elements). The standards in the information level may be viewed as similar to the function of a dictionary, which defines the structure and meaning of words used our language.

Conformance groups are simply a logical grouping of objects. That is, they are objects that all serve a similar function, such as elements dealing with the spatial domain of an ESS, e.g., latitude, longitude and elevation.

Application Level

This level provides standards that identify the rules and procedures for exchanging information data within the National ITS Architecture. Specifically, it defines the syntax of how data is packaged and presented for transmission between electronic devices. The protocols in the level include FTP, SNMP, STMP, TFTP and CORBA. The protocols in the application level can be viewed as being similar to the application of proper grammar and etiquette used to draft a formal letter.

The application level is the primary focus of the suite of NTCIP standards. Where possible it draws from some existing communication standards. However, due to the unique requirements of many specific ITS applications, NTCIP was compelled to extend existing standards as well as develop many new protocols for the transportation industry. Many of the special communication requirements revolve around data exchange between center-to-center and center-to-field applications.

Transport Level

This level defines standards for exchanging information data between two particular points, such as necessary subdivisions of bundled data, subsequent reassembly, routing procedures and network management functions. In general, it defines the rules and procedures to send a packet of Application data from point "A" to point "B" on the network. Protocol is similar to the rules and regulations used by telecommunication companies to connect remotely located devices (e.g., phones, fax machines and/or computers).

Many of the specific requirements in the lower transportation levels (e.g., Transport, Subnetwork and Plant) parallel protocols in the Internet community. As a result, the family of NTCIP standards, which make up the lower levels, are primarily adapted from and extended beyond protocols defined by the OSI.

Subnetwork Level

This level defines rules and procedures for the physical devices used in the communication interface (e.g., modem, network, interface card CSU/DSU, etc.) and how the packaged data is sent over the transmission media (e.g., HDLC, PPP, Ethernet, ATM, etc.). That is it defines the different protocol used to exchange data over different media, cellular link versus a fiber optic cable.

Plant Level – This level defines the communication infrastructure (physical devices and transmission media) used for sending information data between ITS components. Transmission media may be copper wire, coaxial cable, fiber optic cable and/or wireless systems.

As stated before, each level in the NTCIP framework consists of different standards that define rules and procedures about a particular attribute of the information transfer process. The collective levels and each of their different standards is known as the **NTCIP framework**. Many routes are possible through the NTCIP framework by linking the compatible standards from each layer and/or sub layer. The chosen series of standards through the framework is referred to as a **stack**, or a **protocol stack**. Various stacks define the available rules and procedures for transmission of information between ITS devices. Two communicating devices may relay messages using a unique stack or some other series of messages using an entirely different stack, although, it is more typical for the stack to differ at only one or two levels/sublevels. [6]

Standards for Messages, Data, and Communications

NTCIP fact sheets applicable to environmental monitoring using ESS from the information level and the applications level are included in Appendix A.

Additional Resources

Appendix A contains additional resources available on NTCIP and ITS standards, contacts for assistance in procurement and compliancy testing and application areas. Included are Web site URLs and other NTCIP documentation references.

Training

Agencies will benefit greatly through improved understanding of the technical issues surrounding NTCIP and deployment of compliant communication systems from a better NTCIP trained and educated staff. Many training seminars are offered through AASHTO, ITE and NEMA (see the additional resources above) and also through numerous commercial/private firms. In addition, the NTCIP protocol draws heavily from Internet and computer communication protocols. Consequently, there is a wide array of resources available from public libraries, bookstores and the World Wide Web to assist in understanding. [6]

Compliancy Testing

NTCIP compliancy testing may be provided by independent laboratories or consulting firms which specialize in these services. [6]

Meteorological Installation Considerations

There is a broad source of weather information monitored and used by various federal and state agencies, including the Departments of Commerce (DOC), Defense (DOD), and Transportation (DOT). These observing activities are complex and highly diverse and thus require the participation/cooperation of all government organizations, as well as the private sector, largely the commercial aviation industry which represents a big segment of the users of meteorological information [8]. The complexity of coordinating the full scope of meteorological information in use compels that the meteorological data disseminated between diverse federal and commercial entities complies with a standardized architecture and that monitored data is meteorologically sound (accurate). As a result, meteorological guidelines are necessary that direct development of a standardized weather network (to facilitate partnership and data sharing/archiving), assure that monitored weather and road data is accurate, and ensure effective deployment of the wide array of weather related operations and systems in the transportation and meteorological fields, including aviation, surface transportation (e.g., RWIS, winter maintenance) and atmospheric sciences (e.g., weather/surface modeling and forecasting).

Benefits Associated with Meteorological Installation Criteria

Operating agencies and end-users in the transportation industry (as well as partnering agencies) that deploy roadside sensor stations that adhere with established meteorological standards can achieve many benefits, including:

- Meteorologically representative (accurate) data
- Added value to the RWIS of the owning agency as a result of data that is of greatest value and usability by multiple users in the larger meteorological community
- Increased potential for partnering and data dissemination/exchange (with permission) with other levels in the public and private sector (e.g., inter-agency and inter-vendor collaboration)
- Sensor installation built on proven methods

In order to maximize potential benefits, RWIS must be properly implemented and extensively integrated into operations and management. Thus, as a tool it requires proper technical training, skills and in some cases additional developed tools and procedures (e.g., operations and deployment decision support systems/protocols) to take advantage of the full potential of RWIS.

Meteorological Standards Documents Applicable to ESS

The Office of the Federal Coordinator for Meteorology (OFCM) has established broad guidelines (with consideration to the multiple users of weather data) regarding meteorological information and senor siting. Specifically, Federal reports FCM-S4-1994 and FCM-H1-1995 are applicable to surface transportation. Information about the content of these reports and how to access them is contained in Appendix A.

ESS Sensors and their Siting Considerations

The following siting considerations are summarized from established meteorological and RWIS siting recommendations and standards. For more detail regarding specific sensors please refer to appropriate documentation, Federal reports FCM-S4-1994, FCM-H1-1995, SHRP-H-350 and SHRP-H-351.

General

Sensors should be located to be most representative of the intended use of the weather/road information. This may best determined by the deploying agencies qualified staff (preferably a certified meteorologist, RWIS maintenance supervisor and other end-users of the system). In general, sensor stations (towers) should not be placed in obstacle free zones near roads. Sensor exposure should strive to minimize effects from anthropologic and geographical obstruction. The ESS tower is not considered an obstacle to all sensors with the exception of the temperature, dew point and pressure sensors, which should be located as least 10 ft (3 meters) away from other sensors. Also, placement should minimize the influence from disturbed soil and cultivated land to reduce contamination from dust and dirt (it is recognized that this may not be totally avoidable near roads requiring extensive snow and ice control operations).

ESS stations may be used for *monitoring*, *detection* and *prediction* purposes:

- *Monitoring*: When the ESS is being used for monitoring, sensors should be located so meteorological and pavement data will alert personnel to changes in road and weather conditions to allow adequate lead-time to decision makers.

- *Detection*: When the ESS is being use for detection, meteorological and pavement data may be more location specific, such as locations that maintenance personal know are particularly troublesome during winter weather (e.g., bridges, elevated roadways and shadowed roads).

- *Prediction*: ESS used for prediction should be placed to gather meteorological and pavement data that is most representative of the general area.

Ideally, roadside stations should be placed to satisfy more than one of the intended uses.

In brief, the ESS sensor siting guidelines are:

Pavement sensors

Pavement sensors provide information regarding the condition of the road surface (temperature, wet, dry, icy, chemical content) and roadbed (temperature). This information may be used for monitoring, detection or prediction purposes. The following are the conclusion and recommendations taken from the Federal report SHRP-H-350 Volume 1 for sensors placed for **prediction purposes** [9]:

- Pavement sensors should be placed where surface temperatures are representative of general conditions and where specific problems can be detected. Sensors should never be placed where they will be in the shadow of structures or trees.

- Sensors should be placed where the temperature is coldest and traffic is the lightest. In general, this is the inside (passing) lanes of a multilane roadway, which tends to see less traffic. [This may not be accurate in mountainous areas where shadowing and reradiation influences are governing factors.] In large urban areas with a commuter environment, each lane may be heavily traveled. Since the coldest pavement temperatures and the most frequent formations of ice occur in morning hours, sensors should be placed in the wheel track in the inside (passing) lane of the outbound traffic direction, or adjacent to either inside lane in rural areas.

- If the site under consideration is a bridge, the same rules apply, except that sensors should be installed on the deck in the second span from the abutment where the flow of air affects the deck temperature, and in the approach roadway far enough back from the abutment so that the frost penetration does not affect the sensor. In addition, the roadway and bridge deck can frequently have significantly different temperature and conditions.

- Subsurface sensors can be located below surface sensors for economy of installation and maintenance. Care should be taken that the subsurface conditions at sensor locations are representative of subgrades in the area. This would include presence or absence of water, and pockets of unusual materials, such as clay or peat. [The roadbed works as a heat reservoir.] Subsurface sensors are placed about 16-20 in. (0.4-0.5 m) below the pavement surface to determine subgrade temperature. This measurement is important to ascertain whether heat will flow toward or away from the pavement surface, and it has a direct and determining affect on pavement temperature forecasts.

Sensors placed for detection and **monitoring purposes** can use the following guidelines [9]:

- If a highway agency decides to install only one sensor, it should be placed in a wheel track of a passing lane about 18-20 in. (0.4-0.5 m) from the center of the track. If the highway is a commuter route, then the sensor should be placed in the passing lane on the outbound side so it will be least influenced by traffic in the morning when the lowest temperatures are most likely.

- At least two sensors should be placed. On commuter routes, they should be located in the wheel tracks of the passing lane and the outside lane of the outbound side. An alternative could be an outside lane in both directions.

- Sensor location within wheel tracks should also be considered. The center of the track, where most vehicles run, will show the first presence of water ponding. The combination of crown, depth of rut, grade, the expected rate of rainfall or thawing, and tire splash will determine whether there will be standing water in a wheel tack. Sensor placement on the side of wheel tracks is recommended to avoid standing water.

- Care should be taken to ensure that the slope of the road at any location is such that there is no drainage onto a sensor from the shoulder or the median. Sensors should not be placed in the roadway on curves.

- Since vehicle heat influences pavement temperature, placing a sensor in the center of a lane is not recommended. This applies to intersections or roads with frequent stop-and-go traffic and not to roads where vehicles travel at highway speeds. Vehicles traveling at highway speeds contribute little to the energy budget of the road due to conflicting factors between shading of solar irradiance and heat emitted by passing vehicle [10].

- Pavement sensors should be implanted flush with the pavement surface. This will help ensure that moisture does not collect on them (if installed too low). It will also prevent them from being scrubbed off at a rate greater than the surrounding pavement (if installed too high). Care must be exercised in installing sensors in grooved pavement. They should be flush with the top grooves, not the bottom.

- The specific location of pavement sensors with respect to their RPU should be consistent among RPUs so people who monitor the real-time data will not have to remember where each sensors is [located].

Meteorological sensors

Meteorological sensors are used to monitor, detect and predict weather information related to road and weather conditions. Generally, meteorological data gathered may include ambient air temperature, relative humidity (dew point), atmospheric pressure, visibility, wind speed/direction and precipitation (type, intensity, rate, accumulation). Sites more specifically involved in forecasting may monitor shortwave (solar) radiation, longwave (terrestrial) radiation and cloud cover fraction. In order for weather data to be accurate, exposure and placement of sensors should be sited according to standard meteorological siting criteria. As well, roadside location of stations and sensors should be sited with assistance from meteorological analysis, operational considerations (gathered from input from maintenance supervisors or other end users) and/or road thermal analysis that assist in determining troublesome locations and intended use. The following are general meteorological siting criteria regarding proper roadside sensor exposure:

Temperature and Relative Humidity sensors: Temperature sensors are used to measure the ambient circulating air temperature in the area. Hygrometers are used to measure the relative humidity and are typically fixed in the same housing as the temperature sensor. If both devices are not contained in the same housing, the two sensors should be located as close as possible so measurements are concurrent.

The dew point temperature is an important parameter in the formation of ice/moisture on surfaces and is calculated from the relative humidity (RH) parameter. [RH refers to the percentage of water vapor contained in the atmosphere. An RH of 0% indicates that the air contains no moisture and a RH of 100% indicates that the air is saturated, or can hold no more water vapor.] The RH parameter refers to the temperature of an air-vapor mixture at which saturation (RH = 100%) is reached. Thus, it identifies the temperature at which condensation will form as the air is cooled at constant pressure. If the pavement temperature is at or below the dew point temperature moisture may form on the surface (at a higher potential as the gap between the surface and dew temperature increases) and subsequently freeze if the pavement temperature drops below freezing. If the dew point temperature is below freezing and the pavement temperature is below the dew point, conditions are ripe for frost to form. As a result, dew point should be included in the family of ESS indicator parameters.

When siting the sensors for the roadway environment the following guidelines should be followed [from Federal report 8 and 11]:

- Instruments should be located as close as possible to 6 ft (1.8 m) above the surface, or 6 ft above the average maximum snow depth.
- Instruments should be placed over grassy areas, with a second choice of bare ground, rather than pavement.
- Temperature and relative humidity should not be measured from the top of the light standards or sign bridges. The heights of these installations preclude determining representative meteorological values.
- If sensors are not mounted in a housing, they should be protected from radiation from the sun, sky, earth and other surrounding sources and have adequate ventilation.

- Instruments should be positioned in a location that is best representative of the free air circulating in the local area that is not influenced by artificial conditions.

Pressure sensor: The atmospheric pressure is not a standard parameter observed by roadside environmental stations. However, it is of critical importance to atmospheric science studies, as well as to aviation safety and operations. As a result, to make RWIS data of greatest value to all parties involved (such as the National Weather Service) it is recommended to include the ability to monitor atmospheric pressure.

The following meteorological guidelines should be followed when siting pressure sensors on roadside environmental stations [8];

- Instruments should be installed in a weatherproof facility. The weatherproof housing should be vented to the outside if internal venting will affect the altimeter setting value by $\pm$ 0.02 inches of mercury or more.

- Local influences that cause pressure variations due to air flow over the venting should be avoided.

- Instruments should be located as close as possible to 3 ft above the surface, or 3 ft above the average maximum snow depth.

Visibility sensor: The visibility sensor should be located with the following meteorological siting criteria to insure representative data [8]:

- Instrument should be mounted on a stable pedestal, free as possible from jarring and vibration.

- Optical receiver should be pointed in a northerly direction.

- Locate as far as possible from artificial light sources and localized obstructions to vision (e.g., smoke, fog, etc).

- Ten feet above ground is the preferred height or 6 ft above the average maximum snow depth.

- Keep a 6 ft (2 m) area surrounding the sensor clear from vegetation. As well, vegetation within 100 ft (30 m) should be clipped to 10 inches (25 cm). These precautions are necessary to reduce the probability of carbon-based aerosols (e.g., terpenes) and insects from interfering with sensor performance.

- Backscatter-type sensors require a 300 ft (90 m) clear area in the forward (north) octant. Some sensors require an additional clear area. For specific sensor sight requirements, refer to the manufacturer's specifications.

Wind sensor: The speed and direction of air passing a specific point near the surface may be measured using a wind instrument, referred to as an anemometer.

The movement of air is similar to the flow of water in a creek. Objects that obstruct the path of moving fluid, affect the motion (speed, direction, stability) of it, generally the larger the object, the larger the disturbed area downstream. Thus, a good rule of thumb is to locate a wind sensor at least twice as far downwind from an object as the height of the object [11]. If the obstruction is very broad, such as a large group of trees or a building, it is generally recommended to located the wind instrument at least four times as far downwind as the height of the object [11].

Theoretically, the wind speed drops as you approach the ground and is zero at the surface. Therefore, ground disturbance affects generally increase as the height of an anemometer decreases. As a result, sensor height is an important factor in the siting criteria.

Also, it is important to consider the prevailing wind direction and/or in which direction the prevailing winds flow when deciding on the location of an anemometer with respect to surrounding terrain and power systems. The Federal report on RWIS (Volume 2: Implementation guide) offers some advice specific to locating an anemometer near transportation infrastructure [11]:

- Do not install an anemometer downwind from a highway obstruction in the prevailing flow. For example, if the prevailing winds are from the west, do not install an anemometer just east of a bridge.

- In general, take power to a site; do not locate sites because of power availability. The extra cost for burying a few hundred yards of cable or implementing solar power will generally be cost-justified by obtaining more accurate data.

In additions, to insure meteorologically sound data, the anemometer should be located using the following meteorological siting criteria [8]:

- Wind sensors (direction and speed) will be oriented with respect to true north. Adjustments to magnetic north will be accomplished using the systems software.

- A relatively level site should be chosen. The anemometer should be mounted 30 to 33 ft (9 – 10 m) above the average ground height within a 500 ft (150 m) radius.

- Sensor height should not exceed 33 ft (10 m) except as necessary to (a) be at least 15 ft (4.5 m) above the height of any obstruction (e.g., vegetation, building, etc.) within a 500 ft (150 m) radius, and (b) if practical, be at least 10 ft (3 m) higher than the height of any obstruction outside the 500 ft (150 m) radius, but within a 1,000 ft (300 m) radius of the wind.

The Federal RWIS implementation guide offers some additional advice related to ground influences and anemometer height considerations [11]:

- Vehicles may affect anemometer readings at mounting heights below 10 m. Also, the wind sensor should by placed far enough away from highways to not be affected by the winds created by large trucks. [Note: Caltrans District 8, for example, uses a minimum distance of 50 feet from the traveled edge of the highway.]

- The tower should be sited using the criteria for the RPU, given below, as the anemometer is normally fixed to the roadside sensor stations tower.

- If a standard tower cannot be used because of insufficient area in the right-of-way outside of the roadway prism and the clear zone, anemometers can be installed on light standards or utility poles. Anemometers should be placed on top of poles to negate the flow-disturbing effects of the poles. Extension arms to the side of poles are unsatisfactory due to the possibility of air flows being disturbed by the poles.

- If no pole or tower is available, anemometers, like RPUs, can be installed on sign bridges. Care must be taken, however, to ensure that anemometers are installed to minimize disturbances from the signs and sign bridges themselves.

Precipitation sensor: Historically, there have been different types of instruments available to measure precipitation. Theses devices measure precipitation *occurrence*, an important component in snow and ice control, *accumulation* and *rate*. Currently, new commercial electro-optical systems (typically used with RWIS) combine functions into one device while adding a fourth parameter, precipitation type. In addition, the electronic device has the added ability to operate remotely.

Many of the meteorological siting criteria parallel those for the anemometer and visibility sensors. The following are a few to keep in mind [8 and 11]:

- Exposure is a primary consideration for siting the precipitation sensor. Place the instrument in an open an area as possible, avoiding disturbance from natural and artificial obstructions.

- Flow disturbances caused by the tower can hinder the detection and determination of precipitation parameters. As a result, mount the sensor on the prevailing upwind side and as high as possible without disturbing the air flow around the anemometer.

- The sensor should be mounted so the optics are 6 feet (2 m) above the ground or average snow depth. Ten feet (3 m) above ground is the preferred height.

- For double-ended precipitation type discrimination sensors, if possible (considering prevailing wind directions to minimize tower affects) mount the receiver north facing.

Roadside Processing Unit (RPU)

The roadside processing unit is the remote computer located at the tower. It receives analog signals from multiple sensors, converts it to a digital signal and then relays the information to the Central Processing Unit (CPU) via an established communication network. The CPU is the computer that manages communications with all of the RPUs in the field, and also stores, analyzes and reports the data.

The placement of RPUs should be located to address the data needs of the governing agency. The roadside RPU should be located with consideration to the following [9]:

- *Meteorological considerations*: The better the meteorological information, the better the forecasts will be when roadside sensor stations are used as part of the prediction algorithm.

- *Equipment limitation*: Manufacturers of atmospheric sensors specify a distance limit between sensors and their RPU to minimize the influence of ambient noise in the signal. There are also specific minimal distance guidelines between sensors and other obstructions in order to reduce spatial interference affects.

- *Compliancy concerns*: NTCIP compliant procurement specifications should be included as part of the RFP since compliant devices are more effective in achieving system communication and hardware compatibility. Efforts should be made to bring existing systems up to compliant standards.

- *Open systems architecture*: Non-proprietary (open) systems should be the architecture of choice for RPUs and other RWIS technologies. Non-proprietary systems reduce conflicts and hassles with device compliancy, system validation, and device expansions and replacements.

- *Vehicle considerations*: An RPU should be installed as close to the road as possible without being influenced by passing vehicles. If placed too close, during winter road conditions, vehicles can propel slush and de-icing chemicals onto the RPU electronics, atmosphere sensors, and tower.

- *Safety and accuracy factors*: A site should be as safe as possible to prevent vehicles from striking the system. On-ramp gore areas (the pavement triangle between the roadway and the on—ramp) are usually low-impact areas. Along a highway, the area on the right-of-way outside of the roadway prism is also a preferred location if the elevation of the area is within a few feet of the roadway and the area is relatively open and not lined with trees. Trees, cuts and fills preclude gathering representative data.

- *Locate ESS for representative data*: Proximity to power and communications should not be primary considerations. It is better to install an RPU 500 ft (150 m) away from power and pay for cabling than it is to install it in an area not representative of the general conditions (or of the intended use). Also, solar power cells can be used at an RWIS if no commercial power is available. Solar power cells for an RPU cost about the same as 500 ft of trenching. However, solar cells are a theft item and should be properly secured to the tower to prevent removal by unauthorized parties.

- *Locate ESS for intended use*: RPUs should be located to provide representative data with consideration to intended use (monitoring, detection, prediction) by the sponsoring agency, as well as by forecasting services and other external agencies such as the NWS. Intended use should be determined from input from qualified state officials, such as maintenance superiors.

- *Technical assistance*: RPUs and meteorological sensors should be sited with the aid of a meteorologist (preferably licensed) and other qualified RWIS/maintenance staff and end-users.