

Road Weather Sensing: Defining a National Infrastructure

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Introduction

Surveillance of environmental conditions and other aspects of the transportation network is essential to the decision making and control functions of effective highway operations, as supported by the Intelligent Transportation System (ITS). Building a national, integrated, and open surveillance capability is a logical extension of the efforts that led to a national, integrated and open highway system in the United States: The highway infrastructure is the model for an information infrastructure or “infostructure”. Observation of environmental conditions on and around the roadways is just one part of that infostructure, but with important relations to the existing meteorological observation system. Even the meteorological observation system in the U.S. suffers from some fragmentation, but the fragmentation is even more serious for transportation surveillance deployed by numerous local jurisdictions and vendors. This paper describes the vision of a national road-weather sensing infostructure in the U.S., and the initial steps towards that vision.

The Current Situation

Highway surveillance, including road-weather sensing, is neither national, integrated, nor open in the U.S. It could become national in coverage, but will not be national in operation because the highway system is operated by state, local, toll way, and even private jurisdictions. It could still become integrated, as a system in which information is comprehensively available to all interested users, such as maintenance operations, traffic management, emergency management and road users. Open system standards for the ITS, and based on the National ITS Architecture (1), will be necessary for that kind of integration. However, the information is not available now for all road segments, the existing information is not of uniform quality or format, and it is not available to all interested users.

A system of road-weather observations has to be viewed within the larger and overlapping systems of environmental (e.g., weather) observation and surface transportation surveillance. This is depicted in Figure 1.

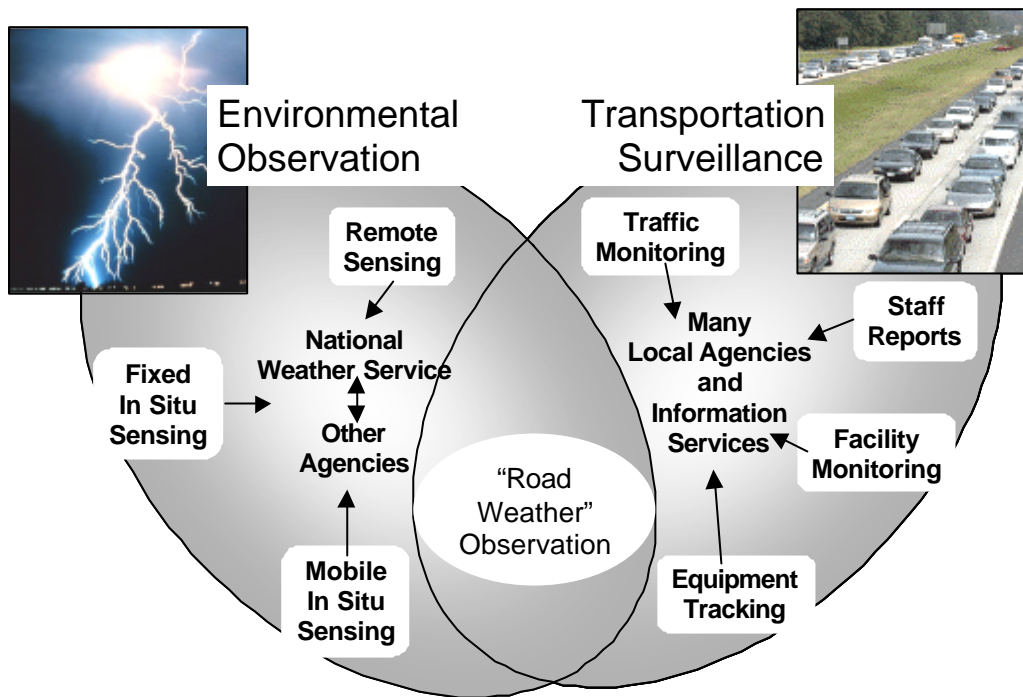


Figure 1: The Overlapping Environmental Observation and Transportation Surveillance Systems

Environmental observation in the U.S. is dominated by the federal agency called the National Oceanic and Atmospheric Agency (NOAA), under the Department of Commerce executive agency. Under NOAA is the National Weather Service (NWS) as the major federal user and processor of environmental information. The NWS *assimilates* all the observational data for use in numerical weather prediction models. Assimilation is the process of cross-checking data (usually based on previous predictive model results) and then putting it in formats (e.g., uniform grids) for model use. Assimilation is both a quality-control process and a way of abstracting more information than is in the individual observations (because the dynamical laws of the environment represented in the predictive models add information when used to compare observations). The National Climatic Data Center (NCDC, mostly for the surface observations) and the National Environmental Satellite, Data and Information Service (NESDIS, mostly for satellite remote sensing data) under NOAA are important repositories and distributors of the observations.

While the NWS, NCDC and NESDIS are important for national environmental information, there are other sources of observations and processed information. Some important observational data, such as the National Lightning Data Network or upper-air observations from aircraft, are from private sources and used by the NWS. The many value-added meteorological services (VAMS) are private providers of forecast information and may serve corporate clients, public agencies and the general public. The private providers rely on the NOAA agencies for many observational data and large-domain numerical weather predictions. There are also many agencies that maintain their own specialized observational systems, as well as some combination of intrinsic and contracted meteorological service. Power utilities, water utilities, and transportation operators are examples.

The types of environmental observation platforms listed are remote sensing (generally taken as satellite, but also radar, etc.), and *in situ* observations (i.e., with sensing proximal to the environment sensed). The latter may be classed as fixed sites and mobile. Most of the remote sensing is under federal auspices. The major agencies involved are NOAA, the Department of Defense, the Federal Aviation Administration within the U.S. Department of Transportation (USDOT) and the National Aeronautics and Space Administration. The Doppler weather radar system, for instance, consists of 167 sites operated by the NWS, the Department of Defense, or the Federal Aviation Administration (the latter also operating 41 air-terminal Doppler radars) (2). There is a similar split in operation of the most important fixed, *in situ*, surface observation system: the Automated Surface Observation System (ASOS) with 991 sites(3). However, these sites are themselves a fraction of the 4221 sites that are federally operated, which does not include many other private or local sensors.

The weather sensing system therefore is diversified but significantly federalized and integrated via NOAA processing. Road weather surveillance, on the other hand, is simply diversified. Road weather may be defined as the weather-related conditions affecting vehicle or highway operations. This includes road-surface condition (friction, obstruction), temperature, visibility (precipitation, blown dust), winds, and electromagnetic effects on ITS equipment (e.g., lightning).

The reason for showing road weather observation at the intersection of environmental sensing and transportation surveillance is that specialized observations are necessary to characterize the road surface and the micro-climate of roadways, as affected by generally larger-scaled atmospheric conditions. The specialized observations could be by any of the means that also serve general transportation monitoring. However, highway agencies have relied on the fixed, *in situ*, roadside, Environmental Sensor Stations (ESS) as shown in Figure 2.

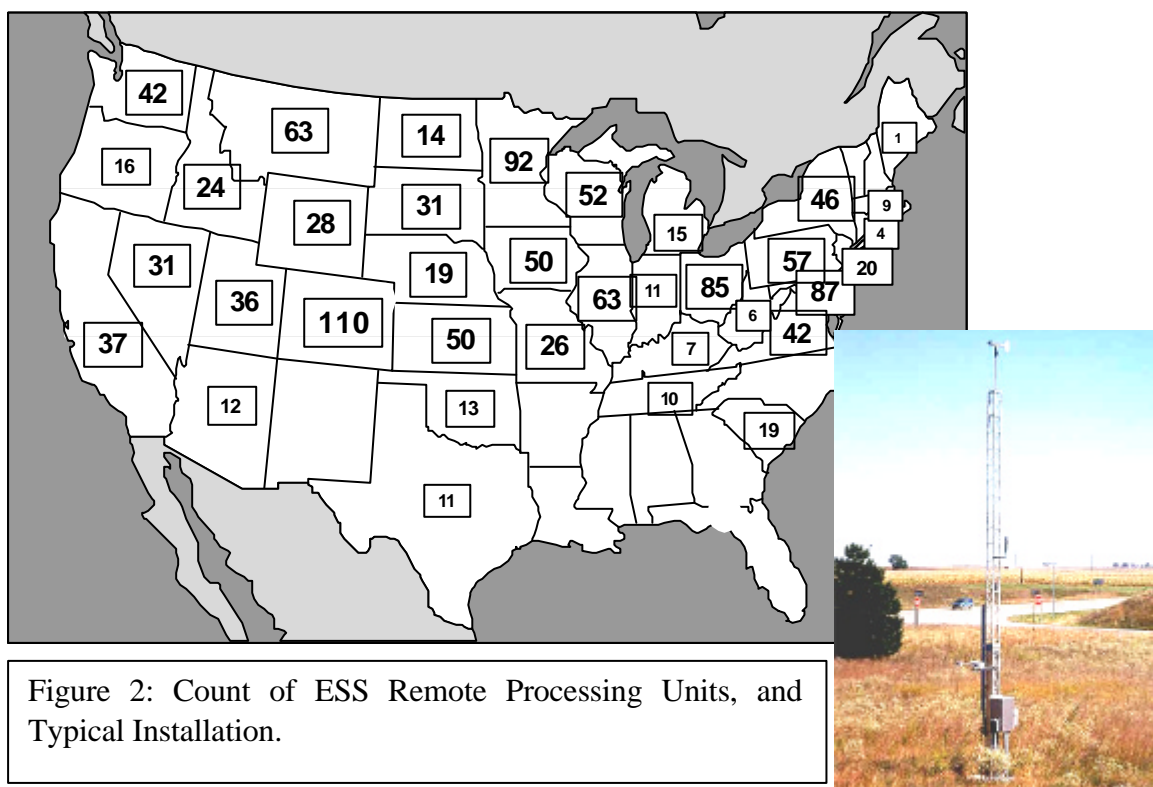


Figure 2: Count of ESS Remote Processing Units, and Typical Installation.

Figure 2 gives the count of remote processing units (RPUs) for ESS, that are operated by or for state or toll way highway agencies. A RPU generally covers a small segment of highway, but possibly with many sensors. There are a total of about 1200 RPUs in the U.S.

The highway system is divided into functional classifications. There are about 4 million route miles of public road in the U.S., but only 662,000 miles are under state administration (4). The National Highway System (NHS) consists of 160,000 route miles (mostly freeway and primary arterials), or 4% of the total, but carries 44% of all vehicle-miles traveled. It may be assumed that most of the ESS RPUs are on the National Highway System, but that means there is only one RPU per 133 route miles, and the great majority of route miles off the National Highway System are not effectively covered.

The federal-aid highway system in the U.S. relies on federal support for construction and the promulgation of standards in conjunction with local (but practically always state highway agency) partners. The federal-aid system (one-quarter of all public route miles) is an integrated and “open” system in the sense that although it is modular by route and jurisdiction, both the physical interfaces and rules of use are uniform and publicized. Facilities such as the ESS are purchased, perhaps with federal dollars, by the states and operated for or by them. The problem is that, as yet, the ESS system is not integrated or open as is the highway system. The data formats from the RPUs vary and may be proprietary. Ownership of the data may reside in the state, or it may reside in the vendors of the ESS to the states. In most cases, the data are not available in any way to third parties. The quality of the data, based on varied calibration and maintenance practices, is not uniform. Very little of the data, which include surface sensing comparable to other environmental observations, is generally available for either NWS or VAMS processing, unless the ESS vendor also acts as a VAMS.

A Vision for Road Weather Sensing

The vision of a national road-weather sensing infostructure (5) is analogous to what is already achieved for the federal-aid highway system, and motivated by two principles: 1) All transportation information should be integrated and open according to the National ITS Architecture, and; 2) Road weather information is important as a part of overall environmental sensing, especially to fill in the terrestrial part of the land-sea-air total environment. The multiple sources and functional sharing of road-weather sensing data are shown in Figure 3.

Figure 3 shows what is properly within the ITS, and how observations and processing must connect with ITS-external entities. The ESS, defined as “belonging” to entities within the ITS, are stipulated by the National ITS Architecture and its standards. While currently deployed mainly as fixed sensors, potentially ESS could also be mobile or remote. There is a nearly-finalized ESS standard (6) concerning the data objects generated by the RPU to application processes (i.e., the “observations” link to management subsystem processes). This is one step toward the open sensing system. There are still layers and access issues to be considered however. In practice, the Internet protocols are convenient for distribution, while compensation and application issues must be resolved regarding data ownership and liability.

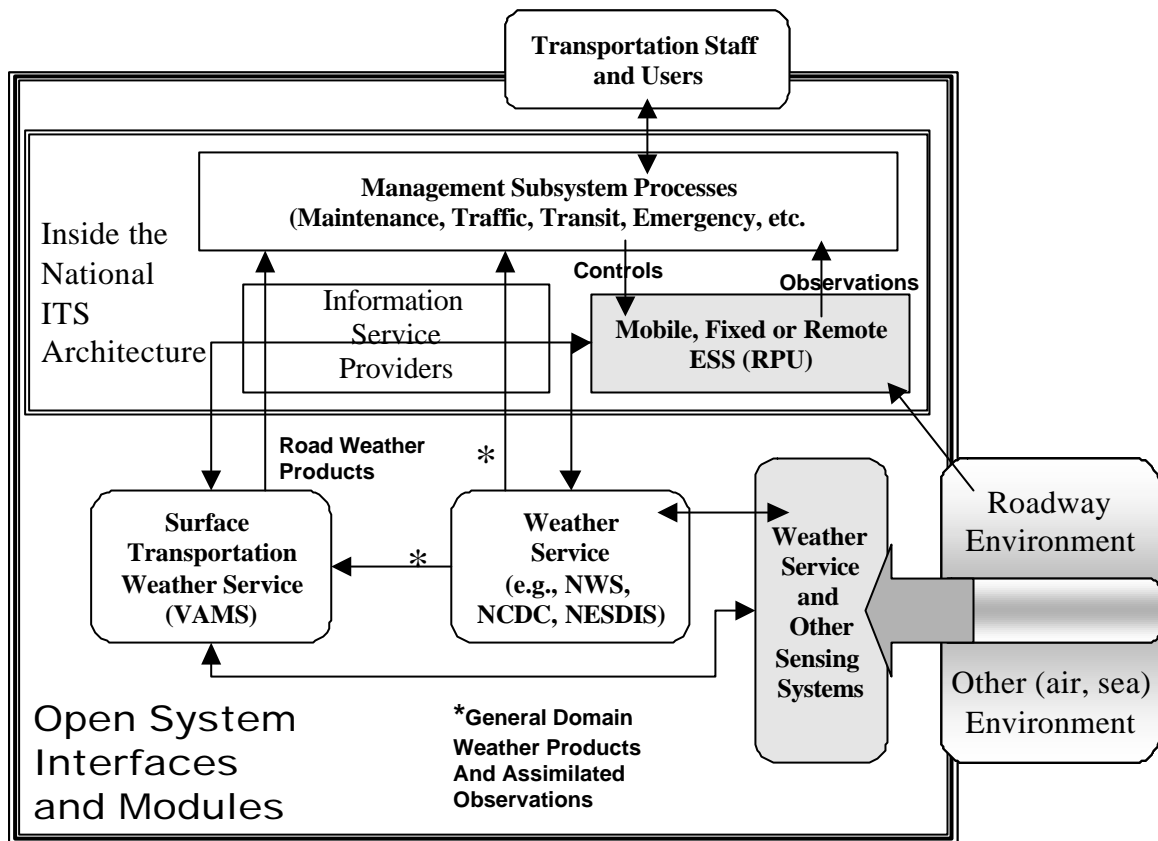


Figure 3: Distribution and Use of Road Weather and Environmental Observations

The National ITS Architecture includes Information Service Providers (ISPs) that mediate much of the information transfer, and the various management subsystems that process information to support their staff. The latter is a decision support function, involving information fusion and presentation tailored to the end users, above and beyond any road weather or general weather processing. The ability to fuse different types of information (e.g., traffic, weather, road weather and treatment resource) in decision support is the ultimate reason for an open system. The Federal Highway Administration has attempted to make the end user needs (the decisions to be made) primary in defining the “upstream” information system. For winter road maintenance managers in particular, a cycle of requirements has been completed (7), resulting in prototype decision support that demonstrates the fusion of many types of environmental information, and production of risk statistics(8).

The international meteorological information system is currently extensively open. New products, such as graphical forecast products, and textual products, still require some interface development for use in the ITS. This includes more use of the Internet, and its Extended Markup Language for defining textual and other data objects. The development of a Road Weather Markup Language by the Japanese is an especially important development in this regard (9).

All types of sensing platforms, and all types of processed environmental information may be relevant to ITS uses and should be available to them. However, the assimilation process strongly implies that observations and forecast models come together outside of the decision support applications. This could be on a national domain, or regionally. There is a similar

argument for the combination of forecast models in order to form ensembles and their statistics. Since the NWS conducts national and regional assimilation, there is a case for expanding their role to include the road weather observations. The institutional diversity of road weather forecast modeling (much of it proprietary) makes it more difficult to foresee ensembling of those models, but the argument for observations logically extends.

Once the integration of all environmental observation is granted, the question arises of how to allocate the economic and operational responsibilities. There are opportunities for shared operation of systems (as for ASOS) and collocation of physical facilities for different sensors. For the latter, an interesting case arises of the use of differential global positioning systems (DGPS), many under transportation auspices, for detection of integrated precipitable water vapor (10). This has led to FHWA and NOAA coordination.

There are still many outstanding questions about the allocation of sensing platforms relative to the end user needs in transportation. For instance, road surface temperature is a key attribute for winter road maintenance. There are various ways of observing and forecasting this. Mobile ESS are probably going to be the economical way to cover the road system adequately, but advances in remote sensing, from aerial vehicles or satellite could be better still. Forecasting can be by time series from direct observation, by spatial prediction using thermal mapping, and by heat balance methods using numerical weather prediction and different levels of initialization by direct observation of road temperature. There is no definitive guidance on this matter, and therefore no definite guidelines on efficient ESS investment. Another variable is the synergy between different kinds of transportation surveillance. Since physical plant (siting, communications and power) is a major cost factor, the economics of ESS are joint with other ITS or other environmental observation infrastructure, and integrated planning is required.

The FHWA is undertaking two major initiatives to address the issue of ESS deployment. One is a general infrastructure requirement. Initial work has been completed to enumerate the needs for transportation surveillance, and quantitative requirements will be analyzed. The Road Weather Management Program within the FHWA contributes to the ESS component. The Road Weather Management Program also launched five research projects in 2001, jointly with the NWS and universities, to investigate different approaches to deploying and using ESS. The FHWA has been working with the Office of the Federal Coordinator for Meteorology (OFCM) since 1999 on both general surface transportation weather needs and an integrated observing network. It is expected that it will be at least two years before these efforts result in firm guidance to deploy the integrated infrastructure. By that time, weather components of the National ITS Architecture should also have matured to provide the open system in conjunction with meteorological open systems. Likewise, State DOTs, particularly through a multi-state research consortium called Aurora, have recognized the need to move towards a national infrastructure. They are currently sponsoring a project to assess their roles in the development of such a system, and how best to achieve the objectives.

Conclusions

Other countries are ahead of the U.S. in integrating their ESS, especially where there is one national operating authority. Canada, with its federal system, is also moving ahead on a national ESS system integrated with their weather service. Experience shows that the reasons for fragmentation in the U.S., among which are size and diversity, are going to take deliberate measures, among several public and private, national and local, parties to meet the goal of an

integrated and open road weather sensing system. Because of the costs and interconnectivities at stake, that goal cannot be separated from either a general surface transportation surveillance system or an integrated environmental observation system. There is an institutional issue and a technical issue of defining an efficient allocation of observations to platforms relative to changing sensor technology, processing capabilities and user expectations.

Through the National ITS Architecture, Aurora, the OFCM, and research sponsored by the Road Weather Management Program, the research and coordinative efforts are underway. However, there is much competition for research and deployment resources in transportation: Road weather concerns have not been funded to the extent that they become major state concerns, nor is surface transportation able to be a significant player among the meteorological interests of the other, dominant, federal agencies. An effort is underway to seek dedicated surface-transportation weather funding in the next federal-aid legislation, to take effect in 2004. A significant increase in funding can catalyze state efforts and create a greater surface transportation presence in the federal arena. That still leaves a large divergence between the public and private sectors.

The U.S. has a mixed system of public meteorological and transportation services, with private VAMS and providers of ESS. This forces public-private coordination at the same time it creates opportunities for autonomous private operation. An open system is a threat to “stovepiped” systems of end-to-end services by either the NWS or VAMS (e.g., from ESS data to road weather prediction). There is little question that there will be public benefit from assimilation/ensembling of all observations and forecasts and an open system of information to feed decision support applications. The challenge is that such a system alters the existing institutional balance, and requires both public and private sector agencies to define new niches for themselves in an open network of transportation and environmental information.

References

- (1) National ITS Architecture, available at <http://www.iteris.com/itsarch/>
- (2) The Federal Plan for Meteorological Services and Supporting Research for FY 2001, OFCM, Table 2.8
- (3) Compiled by the NWS at <http://205.156.54.206/asos/implst.htm>
- (4) Highway Statistics, FHWA, 1999.
- (5) See also the overall surface transportation weather program vision in the Pisano and Nelson paper, and others, in Weather: Making it a National Priority in Surface Transportation, Eleventh Annual ITS America 2001 Meeting,. Available at <http://www.ops.fhwa.dot.gov/weather/publications.htm>
- (6) Information on the ESS standard available at <http://www.ntcip.org/library/quicklink.asp>
- (7) Surface Transportation Weather Decision Support Requirements (STWDSR) Version 2.0. Available as documents 13134 and 13242 at www.its.dot.gov/welcome.htm
- (8) Maintenance Decision Support System Project Plan, available at <http://www.ops.fhwa.dot.gov/weather/>
- (9) Road Weather Markup Language available at <http://www2.ceri.go.jp/eng/its-win/RWML.htm>
- (10) DGPS/IPWV at <http://www-dd.fsl.noaa.gov/gps.html>