INTEGRATRATING WEATHER INFORMATION
INTO AN
INTEGRATED TRANSPORTATION MANAGEMENT SYSTEM

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1. INTRODUCTION

Hazardous weather events can create havoc with transportation along the nation's roadways. Icy roads, significant snowfall events, heavy rainfall, and fog create dangerous travel conditions that slow traffic or often bring it to a standstill. The yearly passage of nor'easters along the eastern seaboard, the occurrence of severe thunderstorms, and occasional encounters with tropical weather systems (tropical storms and hurricanes) create emergency situations that must be managed in an appropriate and timely manner.

Accurate, detailed, and timely weather information is essential to managing surface transportation during these extreme weather events. However, such information must be fully incorporated into an Integrated Transportation Management System (ITMS) to enable decision makers to accurately assess the situation, in real-time, and activate an appropriate response. The Delaware Department of Transportation (DelDOT), in cooperation with the Delaware Emergency Management Agency (DEMA), the University of Delaware, and Computational Geosciences, Inc., is developing such a system.

At the heart of the weather component of this system is the High-Resolution Weather Data System (HRWxDS) developed by Computational Geosciences, Inc. In monitoring hydrometeorological conditions across the State of Delaware, the HRWxDS incorporates weather data from national and local surface observation systems and Doppler weather radars. It will be extended to incorporate road surface sensor measurements as well as a new network of meteorological sensors that are being installed as part of the Delaware Environmental Observing System (DEOS). Thus, the HRWxDS will provide the framework for developing a Road Surface Weather Monitoring and Information System (RSWMIS) to observe changing road conditions that result from variable weather and environmental conditions and other weather components that comprise a fully Integrated Transportation Management System.

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2. IWxTMS FUNCTIONAL CAPABILITY AND DESIGN

The weather component of the ITMS (IWxTMS) will have the capability to monitor, in real-time, all weather conditions statewide that affect surface transportation. This system will provide real-time information on all weather variables (*i.e.*, wind, precipitation, air temperature, atmospheric pressure, and dew point) on a spatial resolution that enables very specific and timely responses to situations that have developed or are in the process of developing. It will have the capability to monitor all weather events, including extreme events, such as ice and snowstorms, floods, and tropical storms/hurricanes. For each of these weather events or another exceptional event that may impact transportation or public safety (*e.g.*, chemical spill or release), event decision support modules will be developed that integrate this data, monitor thresholds, communicate and display appropriate information into an Integrated Transportation Management System.

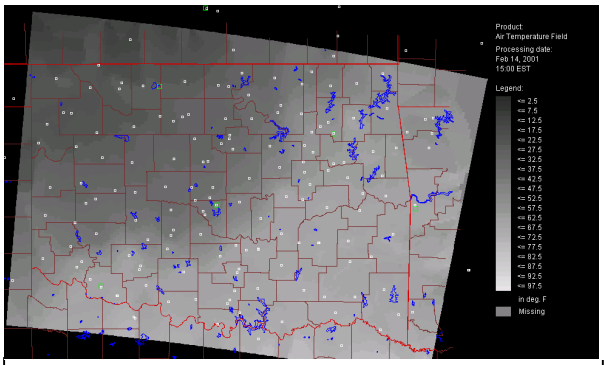

Figure 1: HRWxDS Air Temperature Product showing a cold front moving through Oklahoma on February 14, 2001. There is a 30 degree Fahrenheit temperature differential on each side of the front and a 70-degree differential in the coldest (8 degrees) to the warmest (78 degrees) temperature in the state.

Integrated Decision Support System Components – Individual event decision support system (DSS) modules will be developed for each weather event that can severely impact surface transportation or for weather situations where surface transportation is essential for public safety (*e.g.*, evacuation routes).

DSS modules will be developed for the following weather events and others as appropriate:

- Ice/Snow Storms
- Nor'easters
- Tropical Storms/Hurricanes
- Inland and Flash Flooding
- Coastal Flooding
- High Winds
- Fog Formation

For each of these events, the IWxTMS would provide very detailed, site-specific information regarding the weather conditions and the status of the transportation network. For example, in ice or snowstorms the system will monitor road surface temperatures throughout the state at a 1 km spatial resolution and assess the potential for additional buildup of ice and/or snow by displaying this information in an easily understood format. Key data regarding road surface temperature measurements and companion meteorological measurements will be taken from the Delaware Environmental Observing System (DEOS). Information will be updated every five minutes. Road surface temperature sensors, coupled with the meteorological data, will provide the capability to identify site-specific watches and warnings for particular roads and bridges and site-specific estimates of ice/snow buildup on road surfaces. This information will be used to formulate and direct de-icing plans that precisely target specific roads and bridges. The system would ensure only roads that specifically need to be de-iced would be de-iced and salt would be applied at the exact time to achieve optimum results; thereby, mitigating the amount of salt applied and reducing the damage done to vehicles, bridges, road surfaces, and the environment. Once salt is applied, the system will monitor the salt concentration on the road surfaces, using sensors strategically place in road surfaces, and, the system would again provide alerts - watches and warnings, based on site-specific developing meteorological conditions.

Much of the information developed will be available to the public via the Internet. For example, specific advisories regarding coastal flooding and recommended evacuation routes will be provided to the general public by the coastal flooding decision support component of the system.

3. KEY COMPONENTS

The key components of the IWxTMS are:

- Delaware Environmental Observing System (DEOS)
- DelDOT Telecommunications Network
- The High Resolution Weather Data System (HRWxDS)

Delaware Environmental Observing System (DEOS) is a dense network of meteorologically surface observation stations. DEOS will consist of approximately twenty meteorological observation sites located throughout the State (coupled with existing observational sites in and around Delaware) and will be dedicated to providing real-time weather observations of all important meteorological variables. DEOS also will be extended to incorporate roadway sensors to monitor road temperature and other roadway conditions. These sensors will be strategically located with companion meteorological observation stations.

DelDOT Telecommunications Network is a high-speed fiber optic telecommunication system. The network is currently used to monitor, in real-time, major thoroughfares and key intersections via video cameras strategically positioned throughout the state. DelDOT's network will be used by DEOS to transmit the meteorological and road surface sensor data to the HRWxDS for processing.

The High Resolution Weather Data System (HRWxDS) is the heart of the IWxTMS. It will integrate the surface weather observations from the DEOS, NWS radar data and road sensor measurements and provide the framework for developing an IWxTMS.

The HRWxDS is a real-time, operational weather information system with a client-server architecture. Products generated by the HRWxDS include an entire suite of high-resolution, gridded hydrometeorological data products for a user-defined geographic region (Nixon *et al.*, 1999). The HRWxDS client, a Java-based application, can retrieve products over the Internet or via an internal network (Nixon *et al.*, 2001a,b).

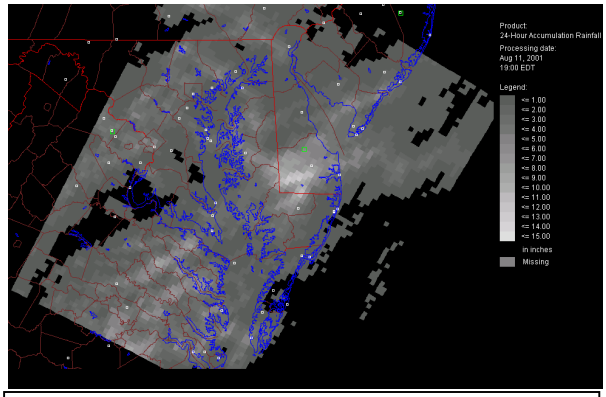

Figure 2: HRWxDS 24-Hour Precipitation Product showing heavy rain in the Delmarva Peninsula on August 11, 2001. An estimated ten inches of rain fell in some areas and caused a small dam to break in Seaford, Delaware.

The HRWxDS can be configured for any geographic region in the conterminous United States. It ingests data from multiple radars as well as both public and private station observation networks. It produces an entire suite of hydrometeorological data products, including:

- Calibrated Doppler radar precipitation -- combines surface raingage observations and radar reflectivity measurements to develop a calibrated radar rainfall estimate (see Legates *et al.*, 1999; Legates, 2000).
- 12 & 24-Hour Precipitation Accumulations
- Storm Total Precipitation Accumulation

- Air Temperature
- Apparent Temperature (Wind Chill and Heat Index)
- Dew Point
- Relative Humidity
- Wind Speed and Direction & Wind Vector
- Solar Radiation
- Potential Temperature and Equivalent Potential Temperature

All HRWxDS products are generated on the Hydrological Rainfall Analysis Project or HRAP grid, which has a spatial resolution of approximately 4 km x 4 km. All products also can be provided in a Geographic Information Systems (GIS) compatible format so that products can be linked with existing hydrologic models and input into a GIS.

The HRWxDS client is the graphical user interface to request, display and analyze the hydrometeorological data products. The client provides the capability to:

- Select the "product source" of products to be retrieved (*e.g.,* the system name or IP address of the server or Local Product Cache).
- Select the product to be retrieved by region, product and time. The client highlights all products available in the database for the selected region by year, month, day, and time of day.
- Customize the client display by specifying the units, time zone, color bar, and overlays (*e.g.*, temperature in Celsius or Fahrenheit, wind speed in meters per second or miles per hour). The user can also create customized color bars.
- Transition easily from product-to-product. The next hour or previous hour of the same product can be selected by pressing the *forward* or *back* button. Similarly, a drop down menu is provided to select a different product for the same hour being displayed.
- Tailor a product "slide show" that keeps selected products continuously displayed. Users can select the specific products and time frames to be included in the slide show or select the "most current" product(s) so that when new products become available, the system will automatically display the latest products.
- Dynamically select overlays, such as basin boundaries, political boundaries, roads, streams, water bodies, and surface observation stations and radars defined for the region.
- Analyze individual grid cell values (e.g., amount of precipitation or specific temperature). Digital products are distributed to the client (verses graphical products) in a NetCDF format.
- Store products locally for post-analysis or off-line investigations.

4. INITIAL DEVELOPMENT / PROTOTYPING

The Coastal Flood Risk Analysis System (CFRAS) Prototype, an initial application to be developed for the IWxTMS, will be designed to monitor and provide decision support for coastal flooding. Coastal flooding is one of the biggest impacts on the transportation network in Delaware and usually is caused by landfall of tropical storms or nor'easters. Low-lying roadways, particularly along the coast, become flooded, limiting avenues of transportation as well as paths of evacuation. Rainfall associated with these weather systems can contribute to the extent to which inland roadways also become locally flooded. Wind speed measurements are particularly vital in that high winds affect the movement of traffic, particularly over exposed bridges that lie along evacuation routes (*e.g.*, the bridges over the Chesapeake & Delaware Canal). Monitoring weather conditions and linking them to the potential for coastal flooding in a spatially distributed fashion is an important tool for both transportation and emergency management officials. A prototype will be developed to provide these officials with real-time assessments of coastal and stream flood risk potentials.

In the initial implementation, an expert operator of the system will input the forecasted high water levels, quantifying the output from models (such as the SLOSH model) into three levels – high, moderate, and low risk – based on the high water level probabilities selected by the expert. Input will be in the form of elevations above mean sea level; risk levels will apply to all areas at or below the specified elevation. The system then will produce a gridded product of risk for each DEM cell and will display the output graphically on screen using shading levels (colors) for risk levels superimposed on the orthophoto DLGs. Data output will be displayed graphically or can be exported in PNG format for printing or later presentation.

Initially, the prototype will use a fixed spatial resolution of 30 meters for the DEM and will focus exclusively on locations within the Inland Bays of Delaware – Rehoboth Bay, Indian River Bay, and Little Assawoman Bay – and the adjacent coastal Atlantic seashore. Flood risk analysis will be assessed on a per-cell basis, where the risk for each cell is calculated individually, based solely on elevation above mean sea level, and not dependent on risk (or other parameters) for adjacent cells. Thus, the prototype will use a simple elevation-based risk assessment algorithm comparing the elevation of the DEM cell to the risk elevation levels selected by the expert.

In addition to the DEM values, ground truth elevation data will be collected of critically important roads, bridge elevations, and other point-specific elevations. These will verify DEM values and improve the prediction of road flooding scenarios.

Summary of Prototype Features

- Based on a digital elevation model of coastal areas for Delaware, 30-meter resolution
- Focus limited to just the Inland Bays of Sussex

County, Delaware
- Results superimposed on orthophoto digital line graphs of USGS quadrangles
- Allows expert interaction to select risk levels
- Risk determined solely by elevation of each DEM grid cell above mean sea-level

Summary of Possible Enhancements Beyond the Prototype
- Variable DEM resolution from 1 kilometer down to 10 meter spatial resolution
- Variable risk levels from a simple risk/no risk dichotomy to a larger selection
- Separate risk levels implemented for each water body
- Risk determination based on "rising water level" or "volume-based" algorithms
- Risk determination from river flooding of upland areas
- Fully graphical region selection
- Output in ARC/INFO coverage files
- Animations and slideshow capability to show temporally-varying risk factors
- Specific location reports of risk assessment
- Web-based access to output for use by on-site emergency management agents

The Delaware Road Surface Weather Monitoring and Information System (RSWMIS) –The main purpose of the RSWMIS will be to provide real-time information on roadway conditions for use by transportation and emergency management personnel. Elements measured by the RSWMIS will include:
- A determination of the presence or absence of water on the roadway in both solid (snow and ice) and liquid form and its depth,
- An evaluation of the freezing point of liquid water (including the effects of salt applications) on the roadway as well as an estimate of the percentage of ice particles present in the surface solution and the percentage of saturation of the chemical solution present on the road surface,
- A measurement of the road surface temperature, and
- A measurement of the near surface atmospheric humidity, for potential fog formation and dew/frost deposition estimation.

Transmission of these data will be in real-time and integrated with a system similar to the HRWxDS for spatial data analysis and extrapolation of values between measurement sites. These pavement sensors will be installed on or near the roadway surface.

In the first year of the DEOS development, a feasibility study will provide information as to the number, type, and expense of each roadway sensor, an assessment of the data transmission requirements (*i.e.*, how often must observations be taken), and the spatial distribution of these proposed sensors. It is expected that this information will be obtained by the completion of the first year of DEOS development so that purchase and installation of these sensors can begin in year two. This is particularly important so that installation of the remaining DMN meteorological stations can be coordinated with the installation of the RSWMIS sensors.

5. SUMMARY

The proposed system will enhance the State's ability to keep roadways open and safe for travel and responses to ice/snow storms that fit the situation can be developed. In addition, evacuation of coastal areas in response to nor'easters and tropical events that cause coastal flooding can be planned, communicated, and monitored.

The public will be better informed regarding weather conditions that could impact their safety. It will keep intrastate and interstate commerce that depends on surface transportation moving safely throughout the state. It will reduce the impact and cost associated with responding to extreme weather events and reduce the detrimental effects of de-icing on road surfaces, bridges, vehicles and the environment. The entire system or individual components can be easily transported to other states and municipalities.

6. REFERENCES

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