OKLAHOMA TRANSPORTATION CENTER

ECONOMIC ENHANCEMENT THROUGH INFRASTRUCTURE STEWARDSHIP

ROADWAY WEATHER INFORMATION SYSTEM AND AUTOMATIC VECHICLE LOCATION (AVL) COORDINATION

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16. ABSTRACT

Roadway Weather Information System and Automatic Vehicle Location Coordination involves the development of an *Inclement Weather Console* that provides a new capability for the state of Oklahoma to monitor weather-related roadway conditions. The goal of this development is that motorist safety might be improved and the damage to highways and bridges caused by the application of deicing agents minimized through the use of the IWC and Decision Support Systems built upon it.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.40	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.9144	meters	m
mi	miles	1.609	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm
ft²	square feet	0.0929	square meters	m²
yd²	square yards	0.8361	square meters	m²
ac	acres	0.4047	hectares	ha
mi²	square miles	2.590	square kilometers	km²
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.0283	cubic meters	m³
yd³	cubic yards	0.7645	cubic meters	m³
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.4536	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.448	Newtons	N
lbf/in²	poundforce per square inch	6.895	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.0394	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yd
km	kilometers	0.6214	miles	mi
		AREA		
mm²	square millimeters	0.00155	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.196	square yards	yd²
ha	hectares	2.471	acres	ac
km²	square kilometers	0.3861	square miles	mi²
		VOLUME		
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallons	gal
m³	cubic meters	35.315	cubic feet	ft³
m³	cubic meters	1.308	cubic yards	yd³
		MASS		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	Newtons	0.2248	poundforce	lbf
kPa	kilopascals	0.1450	poundforce per square inch	lbf/in²

ROADWAY WEATHER INFORMATION SYSTEM AND AUTOMATIC VEHICLE LOCATION (AVL) COORDINATION

FINAL REPORT

February 28, 2011

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1. Executive Summary

This project, "Roadway Weather Information System and Automatic Vehicle Location Coordination", culminated in the development of an *Inclement Weather Console* (IWC) that provides a new capability for the state of Oklahoma to monitor weather-related roadway conditions that pose an obvious safety hazard to the traveling public [1]. The initial version of this Inclement Weather Console is shown in Figure 1.

This console merges data from Automatic Vehicle Location (AVL) instrumentation within Oklahoma Department of Transportation vehicles, weather sensor data from a network of Road Weather Information System (RWIS) stations currently deployed and other real-time weather data including data from the National Oceanographic and Atmospheric Administration (NOAA), the National Weather Service (NWS) and the Oklahoma Climatological Survey into a single visualization framework. During the pilot deployment, this console it is available only to ODOT personnel. Additionally, during this project, we have developed the capability to display RWIS data via ODOT's Advanced Traveler Information System (ATIS) website.

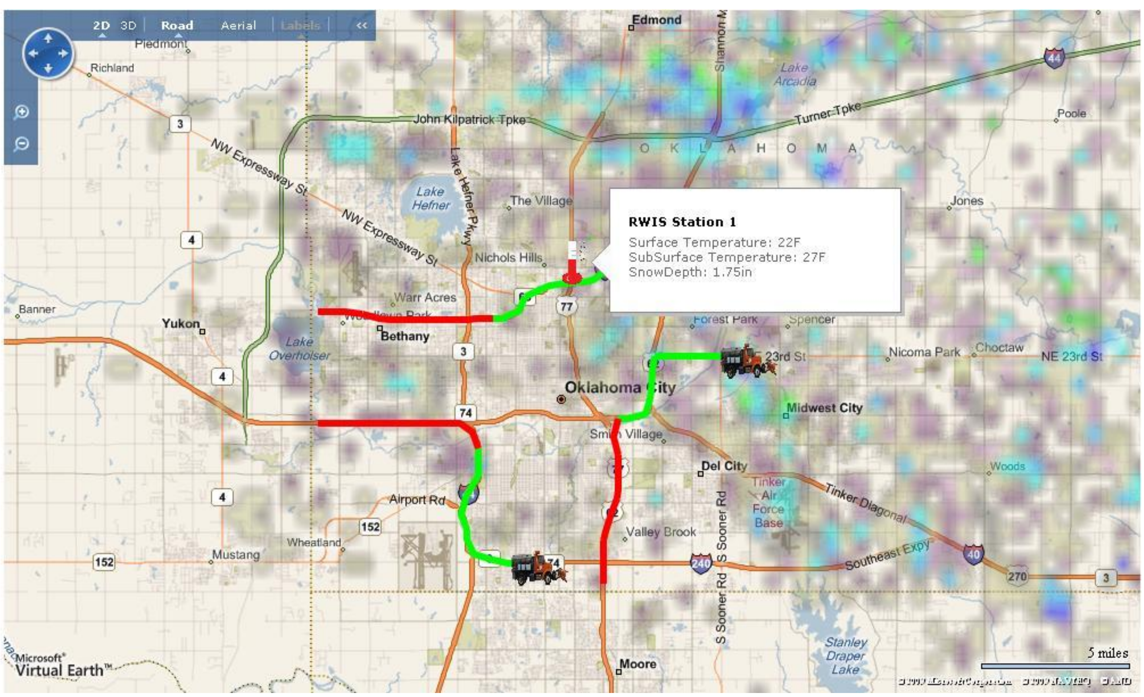


Figure 1: The Inclement Weather Console

This development will improve motorist safety and reduce the damage to highways and bridges caused by the application of deicing agents minimized through the use of the IWC and Decision Support Systems built (DSS) upon it.

Key accomplishments completed during this project include:

- Supported location selection, installation planning and placement of RWIS stations along major arterials in the Oklahoma.
- Incorporated measurement data and camera images from deployed RWIS stations into an integrated visualization framework (IWC).
- Developed similar functionality for displaying complete RWIS sensor data into the ATIS website (currently only available to ODOT logins to the ATIS).
- Developed mobile phone applications for tracking vehicle locations and developed a data stream for AVL data from third-party vendors.
- Plotted AVL data on the IWC. This framework includes the color-coded display of current and historic GPS-based location information of ODOT vehicles.
- Developed database storage and retrieval of AVL locations and routes as well as RWIS measurements. This database allows both the simulated display of a synthesized weather event as well as the off line analysis of real world weather and the effectiveness of the response.
- Integrated other weather information from NWS, NOAA and Oklahoma City Micronet [6].
- Correlated AVL and RWIS data for use in decision support systems (DSS) to advise ODOT personnel on pending roadway hazard conditions.
- Further correlated weather and traffic flow data for DSS purposes. Statistical analysis techniques developed in this area lead to the publication of a paper on traffic flow forecasting at ITSC 2009 [2].

Our system is in the early deployment stage. However, as this system is put to wide use by ODOT, municipal agencies and other transportation stakeholders, it will yield significant benefits in terms of increased traveler safety, in increased effectiveness of the response to poor road conditions and in terms of cost avoidance through optimization of the use of resources in inclement conditions.

2. Introduction

The goals of the project “Roadway Weather Information System and Automatic Vehicle Location Coordination” were to provide a new capability for the state of Oklahoma for the real-time observation of both roadway conditions and the location of vehicles engaged in roadway treatment activities. These capabilities have been merged into a common map console available only to ODOT personnel, called the *IWC.* Additionally, road condition data has been made available to ODOT’s ATIS website.

We have integrated data from Roadway and Weather Information Systems (RWIS) sensors with data from Oklahoma Mesonet [3,4] sensors, the Oklahoma City Micronet [5] sensors, National Weather Service and NOAA weather radar images into a complete view of roadway status. Vehicle location from on-board Global Positioning System (GPS) sensors is sent from instrumented vehicles using cellular radio. Integration is performed by ITS server computers, providing merged displays as well as a complete historical log of weather parameters and treatment activities.

Using this new capability, ODOT personnel will be able to more efficiently direct road treatment crews to road segments, bridges, etc. that are in the most danger of icing and/or flooding. RWIS data is already being used in various states to monitor real-time pavement conditions [6] [7] [8], schedule salt trucks [9], coordinate snow and ice removal [10] [11], to predict road conditions and hazards, and to monitor conditions for maintenance activities like pavement marking and concrete pours [12], and has been used in Indiana in conjuction with AVL to coordinate chemical deployment and snow/ice removal.

The result of these activities provides ODOT with new capabilities for directing road treatment crews. The primary aims of this system are **to improve motorist safety and to minimize damage to highways and bridges caused by the application of deicing agents** [13]. This transformative technology will turn the approach from one of de-icing to anti-icing and enable the application of preventative chemicals before ice forms, reducing the amount of chemicals and salt used while improving safety [14]. The software developed as part of this project also offers the capability to inform the public in real-time of current road conditions, thereby giving them and other public, private, and reporting agencies the ability to make informed decisions regarding the use of public thoroughfares during inclement weather. Further, increased efficiency in the application of Oklahoma's limited resources to respond to inclement weather will result in increased public safety while doing as little damage to the transportation infrastructure as possible. Real-time data and data logging is provided in addition to hosting the basis for institutionalizing best-practices for roadway treatment and developing a fine-tuned set of decision support systems for chemical mixes and vehicle deployment.

2.1 Objectives

The objectives of this project were to:

- Assist ODOT contractors with the deployment of RWIS stations along Interstate Highways in Oklahoma, particularly in the areas of networking, communication, and integration into ODOT's ITS network.
- Establish mechanisms to feed data from deployed AVL and RWIS devices into an integrated visualization framework.
- Develop database storage and retrieval of both AVL locations and routes as well as RWIS measurements.
- Develop an AVL system for ODOTs weather-response vehicles using GPS networked data via GPRS cellar communication and perform AVL map plotting using an internet-based mapping API.
- Develop color-coded visualization for these routes and measurements using the mapping API.
- Provide public Advanced Traveler Information System (ATIS) with basic RWIS data and travel-time predictions
- Develop decision support systems (DSS) to advise ODOT personnel on pending roadway hazard conditions requiring chemical application, strategic and/or optimal resource routing, chemical mixes, application rates, etc.
- Utilize RWIS information in the formulation of travel-time estimates
- Study vehicle instrumentation options for chemical weight, chemical spreading rate, vehicle speed, plow blade status (up or down), etc. and networking options.
- Design console views and logs of traction and deicing treatment effectiveness.
- Integrate other current weather conditions and pending weather conditions from Mesonet and the Oklahoma City Micronet into the visualization framework and DSS.

2.2 Accomplishments

This project consisted of 17 proposed milestones:

- Assist ODOT contractors with RWIS deployment, networking and communication, and integration into the ITS network.

- Develop database storage and retrieval of RWIS measurements.
- Develop AVL using GPS networked data via GPRS cellar communication.
- Develop AVL map plotting using Bing Maps APIs.
- Develop database archiving of vehicle routes.
- Develop RWIS color-coded measurements and plotting using Bing Maps.
- Integrate RWIS and AVL data onto common map plots.
- Provide public Advanced Traveler Information System (ATIS) with basic RWIS data.
- Perform weather data correlations on RWIS stored data for future design of decision support systems (DSS).
- Study vehicle instrumentation options for chemical weight, chemical spreading rate, vehicle speed, plow blade status (up or down), etc. and networking options.
- Develop decision support systems (DSS) to advise ODOT personnel on pending roadway hazard conditions requiring chemical application, strategic and/or optimal resource routing, chemical mixes, application rates, etc.
- Integrate other current weather conditions and pending weather conditions from Mesonet into DSS.
- Augment ATIS web pages with additional RWIS and Mesonet data.
- Integrate anticipated traffic rates into DSS to achieve maximum public safety.
- Install sensors on selected vehicles for monitoring vehicle status: chemical weight, application rate, speed, blade status, etc.
- Develop networking options for vehicle status reporting.
- Design console views and logs for evaluating treatment effectiveness.

Each of these milestones was completed. As a result of this project, our team assisted with the deployment and integration of 6 RWIS stations along Oklahoma Interstate Highways and instrumented snowplows with location and telemetry units provided by a third-party vendor for testing. The IWC, developed as the main deliverable of this project, is being tested and evaluated by ODOT Divisions. RWIS information has also been provided via Oklahoma ATIS site. Significant benefits will be achieved through this ATIS deployment and through broader deployment of the IWC. These technologies which have been transferred to ODOT should result in increased effectiveness of the response to poor road conditions and in cost avoidance through optimization of the use of resources in inclement conditions.

3. AVL and RWIS Integration

Figure 2: RWIS Deployment in Weatherford, OK

Figure 3: Location of the 6 deployed RWIS stations

The acquisition of roadway weather data has long been shown to typically have a favorable cost to benefit ratio [15]. As part of this project, we assisted ODOT in their evaluation of a pilot RWIS deployment by providing technical and logistical support to ODOT contractors in the installation and network integration of several Road Weather Information System (RWIS) stations. Figure 2 shows the deployment of an RWIS station near Weatherford, OK being deployed by Vaisala, one of the two vendors of RWIS stations ODOT has currently deployed. While some RWIS stations, including models from Vaisala are non-invasive, having sensor only above the roadway, we assisted with deployments also involving in-pavement sensors. [16]

This deployment was performed with consultation and participation of the OU ITS Lab Manager. We are further assisting ODOT in the evaluation of the deployed RWIS stations, manufactured from various vendors. Figure 3 shows the locations of the 6 RWIS sites deployed in Oklahoma at the end of Year 1 of this project. Note, two RWIS sites are co-located in Oklahoma City. Optimal placement of RWIS stations has been shown to be crucial in ensuring a source of useful data regarding roadside conditions [17].

3.1 Data Acquisition

Two different vendors have been contracted thus far to install RWIS stations along Oklahoma Highways, Vaisala and Surface Systems (SSI). By working with both of these vendors, we established mechanisms to automatically retrieve RWIS sensor data from stations manufactured by either Vaisala and SSI. Stations from both manufacturers send measurement data wirelessly [18] to the vendor that in turn serves as our data provider. Note that stations from each vendor feature different measurement capabilities, as well as how their measurements are delivered to us; Vaisala provides us XML data using the National Transportation Communications for ITS Protocol (NTCIP) [19]. A sample of this data is shown in Figure 4. Use of NTCIP has the benefit that software developed based on it have interoperability with any devices that support it. Similar benefits from interoperable XML formats and data management were perceived in a proof-of-concept nationwide RWIS deployment in Canada [20].


```
<ntcipMessage source="example_station"
lat="4252792"
lon="-11140372"
type="obs"
dataTime="20061206T223603"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="http://ice.tmi.vaisala.com/ntcip.xsd">

<value name="essSubSurfaceTemperature.1">-17</value>
<value name="essSubSurfaceMoisture.1">101</value>
<value name="essSubSurfaceSensorError.1">2</value>
<value name="essSurfaceStatus.1">4</value>
<value name="essSurfaceTemperature.1">56</value>
<value name="essSurfaceWaterDepth.1">0</value>
<value name="essSurfaceSalinity.1">0</value>
<value name="essPavementTemperature.1">31</value>
<value name="essSurfaceConductivity.1">1</value>
<value name="essSurfaceFreezePoint.1">0</value>
<value name="essSurfaceBlackIceSignal.1">2</value>
…
```


Figure 4: Sample segment of NTCIP XML data from an RWIS station

However, SSI can only provide us with a website from which we are extracting and parsing the data. We have developed a mySQL database for the storage and retrieval of this sensor data. The structure of the MySQL database that was developed to store RWIS data is relatively simple. The database was setup to be resident on the server hosting the IWC. The database is named *RWIS*, and there are three primary tables: *weather_stations*, *weather_values*, and *ssi_values*.

The *weather_stations* table contains a list of all RWIS stations with an ID, name, lat, long, type (obs or ssi, where obs is used to indicate Vaisala RWIS stations), source (pertaining to file name or site id depending on type), and image_name. The structure of this table is shown in Figure 5.

```
mysql> select * from weather_stations;
+----+--------------------+-----------+------------+------+------------------+---------------------------+
| ID | name               | lat       | long       | type | source           | image_name                |
+----+--------------------+-----------+------------+------+------------------+---------------------------+
|  1 | Weatherford       | 35.463672 |  -97.461875 | obs  | Weatherford      | 02264dd2_05c607a7_cam1.jpg |
|  2 | Reno               | 35.536384 |  -98.642461 | obs  | Reno             | 02235987_05BB960A_cam1.jpg |
|  3 | Chikaskia_River    | 36.906546 |  -97.353135 | obs  | Chikaskia_River  | 0233247F_FA3282A0_cam1.jpg |
|  4 | I-35_and_SH51      | 36.115961 |  -97.345223 | ssi  | 711001           | 10_60_10_2.jpg            |
|  5 | I-40_and_Stateline | 35.226666 | -100.000112 | ssi  | 711002           | 68_25_236_242.jpg         |
+----+--------------------+-----------+------------+------+------------------+---------------------------+
```

Figure 5: Sample of *weather_stations* database table

The *weather_values* table contains the ID (autogenerated) and stationID which matches the ID field in the *weather_stations* table. The structure of this table is shown in Figure 6. The *weather_values* table also contains several fields that store sensor data obtained from the RWIS stations. These fields include *ess* and *spectro* fields that correspond to fields in the XML file provided by Vaisala.

```
mysql> desc weather_values;
+------------------------------+------------------+------+-----+---------+----------------+
| Field                        | Type             | Null | Key | Default | Extra          |
+------------------------------+------------------+------+-----+---------+----------------+
| ID                           | int(10) unsigned | NO   | PRI | NULL    | auto_increment |
| stationID                    | int(10) unsigned | NO   | MUL |         |                |
| essSubSurfaceTemperature1    | double           | NO   |     |         |                |
| essSurfaceTemperature1       | double           | NO   |     |         |                |
| essSurfaceStatus1            | varchar(50)      | NO   |     |         |                |
| essSurfaceTemperature2       | double           | NO   |     |         |                |
| spectroSurfaceFrictionIndex1 | double           | NO   |     |         |                |
| spectroSurfaceIceLayer1      | double           | NO   |     |         |                |
| spectroSurfaceSnowLayer1     | double           | NO   |     |         |                |
| spectroSurfaceWaterLayer1    | double           | NO   |     |         |                |
| spectroSurfaceTemperature1   | double           | NO   |     |         |                |
| spectroSurfaceStatus1        | double           | NO   |     |         |                |
| spectroAirTemperature1       | double           | NO   |     |         |                |
| spectroRelativeHumidity1     | double           | NO   |     |         |                |
| spectroDewpointTemp1         | double           | NO   |     |         |                |
| dt                           | datetime         | NO   |     |         |                |
| image                        | blob             | NO   |     |         |                |
| essAirTemperature1           | double           | NO   |     |         |                |
| image_filename               | varchar(70)      | NO   |     |         |                |
+------------------------------+------------------+------+-----+---------+----------------+
```

Figure 6: Sample of *weather_values* database table

At the time of this report the *weather_values* tables has accumulated 182675 entries.

The *ssi_values* table is simlar to *weather_values*, containing the same fields except for the sensor data storage fields, which are identical to those provided by the SSI provider. The structure of this table is shown in Figure 7.

```
mysql> desc ssi_values;
+-------------------+------------------+------+-----+---------+----------------+
| Field             | Type             | Null | Key | Default | Extra          |
+-------------------+------------------+------+-----+---------+----------------+
| id                | int(10) unsigned | NO   | PRI | NULL    | auto_increment |
| stationID         | int(10) unsigned | NO   | MUL | NULL    |                |
| deck_surface_temp | double           | NO   |     | NULL    |                |
| road_surface_temp | double           | NO   |     | NULL    |                |
| sub_surface_temp  | double           | NO   |     | NULL    |                |
| opti_q            | varchar(60)      | NO   |     | DRY     |                |
| dt                | datetime         | NO   |     | NULL    |                |
| image_filename    | varchar(60)      | YES  |     | NULL    |                |
+-------------------+------------------+------+-----+---------+----------------+
```

Figure 7: Sample of *ssi_values* database table

At the time of this report the *ssi_values* tables has accumulated 304144 entries.

Three services were developed in conjunction with the MySQL database in order to obtain and store the data from the RWIS stations. The first service to be developed, named *getRWIS*, connects to the FTP service provided by Vaisala at ftp://birice.vaisala.com. It downloads all relevant XML and image files from the FTP service. It then searches each XML file and attempts to match the *source* field in the XML with the *source* field in the *weather_stations* database. When a match is found, it indicates that the following section of XML contains sensor data information for one of the deployed RWIS stations. That sensor information is then extracted. The script then uses the corresponding *image_name* field from the *weather_stations* table and a copy is attempted, copying the file specified in the *image_name* field from the current working directory in the FTP service to an *images* directory resident on the server running the script. The image is copied with a name containing the date and time. The extracted sensor data and paired *image_name* are then inserted into the *weather_values* table in the database.

As SSI RWIS data is only provided on a webpage, a separate service was required to obtain SSI data. This service, named *getSSI*, parses the data from the RWISONLINE website at www.rwisonline.com/scanweb/swlogin.asp. This website is shown in Figure 8.

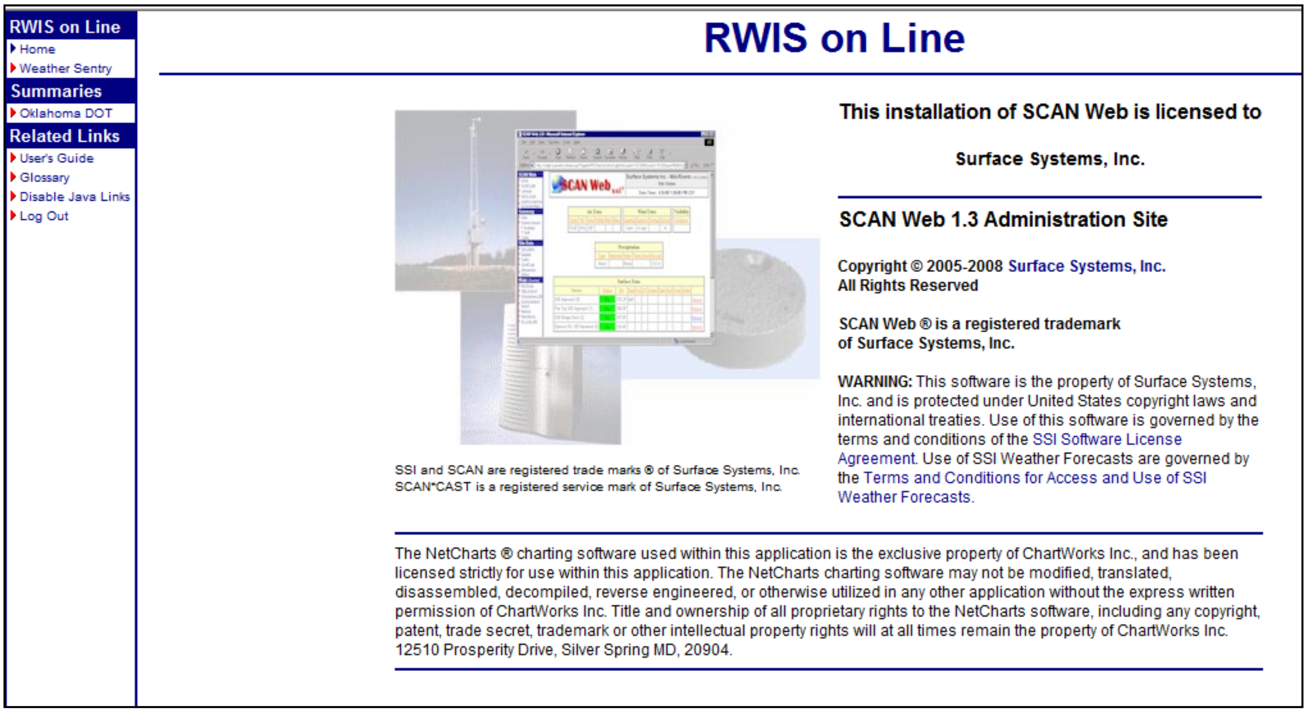


Figure 8: RWISONLINE Website – Home Page

Because the information on the site is intended to be primarily viewed by humans who are able to navigate the menu on the left, developing a method by which RWIS data could be automatically obtained from the site and stored presented a challenge.

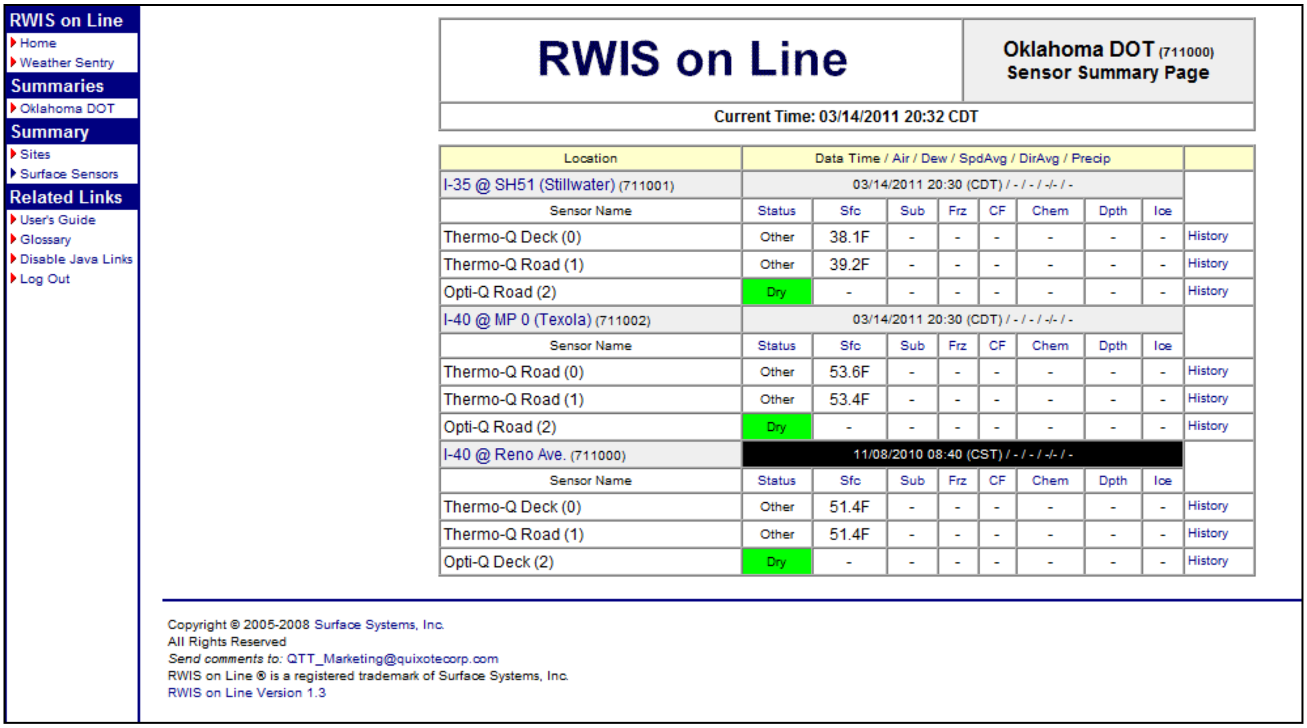


Figure 9: RWISONLINE Website – Sample Data Page

One of the site pages containing RWIS data is shown in Figure 9. These site pages make use of parameters passed to the page in the URL in order to determine what data to display. For example, the address for the site in Figure 9 is: http://rwis.vaisala.com/scanweb/SWFrame.asp?Pageid=SfSummary&Groupid=711000&Siteid=&DisplayClass=Java&SenType=All .

These site addresses were analyzed to determine which parameters could be used to bring up pages with the data that was desired. Once the page structure of the site had been determined, the *getSSI* script was developed to be able to connect to the site, submit the required username and password, and submit the correct parameters. The script was then capable of obtaining the raw HTML from the site, within which was the sought after data. The script was then further developed to be capable of searching through the raw HTML to locate the desired RWIS data, extracting that data from the HTML, and storing it in the *ssi_values* table of the database.

An additional image management structure was developed in order to be able to concurrently use images from both Vaisala and SSI. For the Vaisala RWIS stations, the *getRWIS* script copies images to from the FTP service to the *images* directory (a new image with timestamp in the filename) and a *rwis_ssi* directory on the server (overwriting the latest image). For the Vaisala stations, the *image_name* column in the database is the filename obtained from the FTP service, but that image is then copied to the other directories using the *source* column, as *source*.jpg.

Images from the cameras at the SSI RWIS stations are not available from the SSI website. These images are directly uploaded to the to the *rwis_ssi* directory on the server via FTP by the cameras themselves. When the *getSSI* script is run, it copies images directly from the *rwis_ssi* directory to the *images* directory. The filename that the script tries to copy from the *rwis_ssi* directory is the *image_name* column from the database. The images that are copied to the *images* directory by the *getSSI* script are modified to have a filename containing the date and time, just like the filenames for the images placed in the *images* directory by the getRWIS script. This structure ensures that filenames for image files from both Vaisala and SSI stations are named according to identical format rules. It also ensures that the *rwis_ssi* directory on the server always contains the latest single image from both Vaisala and SSI stations and that the *images* directory always contains multiple historical images from both Vaisala and SSI stations.

The scripts above continuously save RWIS images to the server on which they are run, and in order to prevent the server from running out of disk space, a third service was developed to clear old images. This service, called *cleanRWIS*, removes all images from the *images* directory that are more than two days old at the time that the service is run.

It should be noted that several names used in the different services described above must match up correctly in order for data to be successfully obtained. This is largely a result of the requirement to obtain and concurrently use data from two very different services. In order to successfully acquire images, the *image_name* column in the *weather_stations* table needs to match the image obtained via FTP download in the case of Vaisala devices. In the case of SSI devices, the *image_name* column needs the match the filename of the images being uploaded via FTP from the cameras.

Aside from the image names, other columns also need to be correctly specified in order for these scripts to function correctly. For Vaisala devices, the *source* column in the database needs to match the device identifier given in the XML downloaded from Vaisala. For SSI devices, the *source* column needs to match the id given to the RWIS station on the parsed website. That id number is also currently hardcoded into the *getSSI* script and must also match there.

The greatest liability in the data acquisition process is the parsing of the RWISONLINE website in order to obtain data for SSI RWIS stations. This is a necessary method as there is no alternative, but the method is prone to problems as the website is solely maintained by SSI. Any slight modifications to the URL options or page layouts of their site could cause our service to no longer function.

3.2 IWC Mapping Solution

For mapping AVL data and co-displaying those locations with RWIS station readings, we initially developed a prototype system using Google Earth [20] and Google Maps [21]. However, deploying our console so that it could be used as either an ODOT internal, access-controlled site or as a publicly available traveler information site would require the licensing of the Google Maps Premier API. For this reason we investigated various mapping platforms and demonstrated two options to Alan Stevenson, ODOT Technology Services Division, one based on Google Maps and one based on Microsoft Bing Maps [22]. Bing Maps proved to be superior in both capabilities and licensing terms and price.

We had also considered using MapScript as a mapping solution for the IWC. MapScript is an open source mapping solution using the PHP programming language that was developed by the University of Minnesota. It is capable of generating map images when given GIS data. The primary benefit to the use of MapScript is the cost of the solution. MapScript is free to use, while alternative GIS solutions such as ESRI software, Google maps, or Bing maps can entail licensing fees. A further benefit to the use of MapScript as a mapping solution is that it is identical to the mapping solution used in several components of the Oklahoma ITS network, including ITS consoles that are in use around the state and the Oklahoma ATIS. This would allow any common functionality between these components and the IWC to potentially share code and human resources.

The single greatest drawback to the selection of MapScript as a mapping solution is that it is considerably more difficult to use than commercial mapping solutions. The solution has a steep learning curve for implementation. Development of the features required in the IWC would be time-intensive, and usage of a mapping solution such as Google Maps or Bing Maps results in cleaner code that is more quickly developed and more easily maintained. In addition, the solution requires that all GIS data be provided by the implementer. The use of Google Maps or Bing Maps as a solution frees the implementer from having to work through the details of mapping all highways, political boundaries, and structures that may be desires. Moreover, Google Maps and Bing Maps provide satellite imagery that would be very difficult to include in a MapScript mapping solution. Because the IWC is a brand new pilot project that needs to be efficiently developed and explored, the use of either Google Maps or Bing Maps turned out to be preferable to an attempt to use MapScript as a mapping solution.

When evaluating the capabilities of Google Maps and Bing Maps, three main areas were considered: ease of programming, speed of the map, and features available from the API. Both mapping applications provided the main features needed to implement the IWC. This includes the ability to display icons on the map using latitude/longitude, the ability to render shapes (especially lines) on the map and the ability to overlay other data, such as weather radar, on the map. Programming the maps also proved to be similar. Both provided detailed API documentation on how to place elements on the map as well as how to overlay other images. With both the API features and ease of programming being relatively similar, the critical differences in the two platforms were in the speed/performance of drawing a map. Google Maps showed significant slowdown when creating maps with a large number of tracked objects. This was especially true when drawing lines that each contained anywhere from 5 to 10 points.

Displaying historical trails for tracked vehicles required a large number of points to be plotted. Because the trails are broken into 15-minute segments, displaying a 3-hour trail requires 180 to 360 points to be plotted. This took approximately 10 seconds for Google Maps to draw the map and often resulted in the crashing of our Inclement Weather Console site. Bing Maps shows no measureable slowdown when adding the same number of points. Sample code to draw this historical train behind vehicles is shown in Figure 10.

```
eval("polyLineT" + truckID + "g" + oldGroup + " = new VEShape(VEShapeType.Polyline, mapPoints);");
eval("polyLineT" + truckID + "g" + oldGroup + ".SetLineWidth(6);");
eval("polyLineT" + truckID + "g" + oldGroup + ".HideIcon();");
eval("polyLineT" + truckID + "g" + oldGroup + ".SetDescription(\"Average Speed: "+avgSpeed+"\");");
eval("polyLineT" + truckID + "g" + oldGroup + ".SetLineColor(colorObject);");
eval("ShapeLayerT" + truckID + ".AddShape(polyLineT" + truckID + "g" + oldGroup + ");");
```

Figure 10: Microsoft Bing Maps API calls to draw the historical vehicle trail. truckID is the unique ID for the truck, oldGroup is the hour group the line segment belongs to (lessthan 1 hour ago, between 1 and 3 hours ago, more than 3 hours ago) and thus controls the color of the particular line segment. avgSpeed is calculated as the line segment is built. Additional parameters could be added to this as the segment is built (such as spread rate, chemical mixture etc) and then added to the segment in the same manner. Note that each truck belongs to its own shape layer, allowing all of the lines and icons pertaining to a particular truck to be removed at once with relative ease.

Even if Google Maps was able to generate maps with large numbers of objects, the generated map was then extremely slow to respond to user interaction. Bing Maps improves performance on such maps by not drawing icons that are located off of the currently displayed map, whereas Google Maps draws these objects regardless of whether they will be on the visible map or not. As a result, no slowdown was noticeable in user interaction on Bing Maps containing large numbers of objects, whereas Google Maps were essentially unusable.

The licensing plans for Google Maps and Bing Maps were both found to be on the order of several thousand dollars per year. After contacting both vendors, we were provided quotes for usage licenses. A Google Maps license is free to use for a basic, public, non-commercial site. Otherwise, the pricing at the time of the beginning of the project for a Google Maps license was $1 per month per map item with a $10,000 per year minimum. The Bing Maps licensing options follow a slightly different structure. At the time of our quote, a Bing Maps license cost a base price of $4,000 per year and an additional $3,200 per year for 100,000 transactions per month. Bing Maps transactions are individual communications with the Bing Maps servers, and additional plans from Bing Maps are available that allow more transactions. Although the free licensing plan for Google Maps is attractive, this license does not apply to the IWC as the site is access-controlled. This makes the Bing Maps licensing options somewhat cheaper than those for Google Maps, especially for a relatively low-traffic application such as the IWC.

The significant performance difference discussed above make Microsoft Bing Maps an attractive choice for the implementation of our console. This reason, combined with the more reasonable licensing terms of Microsoft Bing Maps, led us to be directed by our ODOT technical advisor to continue development using the Bing Maps substrate.

3.3 IWC Capabilities

Figure 1 showed an example of the Inclement Weather Console implemented using Bing Maps. Note that because the mouse is over the simulated RWIS station, selected temperature and precipitation sensor readings are displayed. On the advice of the Oklahoma Climatological Survey, we added a timestamp to the visualization of these sensor readings to prevent data which is out-of-date due to network connectivity issues from influencing decision makers. This figure also displays two-hour historical location information for the tracked vehicles (green—one hour old; red—two hours old). The display of this information is adjustable, and allows the console operator to see which roadways have been treated within the chosen timeframe. Figure 1 further demonstrates the NOAA base reflectivity radar image that we have incorporated into our console.

Figure 11 shows an interface to control which weather and vehicle information is displayed. Each vehicle that is being tracked can be selected or deselected, the historical location trail can be displayed as a single fading line segment or as three distinct segments, and the appearance of the weather radar image can be controlled.

Because this visualization system was developed while the RWIS and AVL deployments are ongoing, it was necessary to develop the ability to replay events from data stored in our database. This is an important aspect of the decision support system being developed as planners and decision makers will require the ability to analyze the effectiveness of inclement weather response strategies. However, this was first used to display simulated vehicle and weather sensor readings while the feed for these sensors was not online. Using AJAX code, we are able to update our map console seamlessly without requiring a reload of the webpage. A C# application was written to support both real-time vehicle travel simulation as well as to support the input of large synthetic latitude and longitude data sets. GPS-derived latitude and longitude data sets were provided by ODOT for several vehicle routes controlled by the same interface shown in the bottom of Figure 8. Initially, the simulation times were slow when plotting large amounts of data points. This performance issue was largely solved by moving the data point encoding to a PHP script.

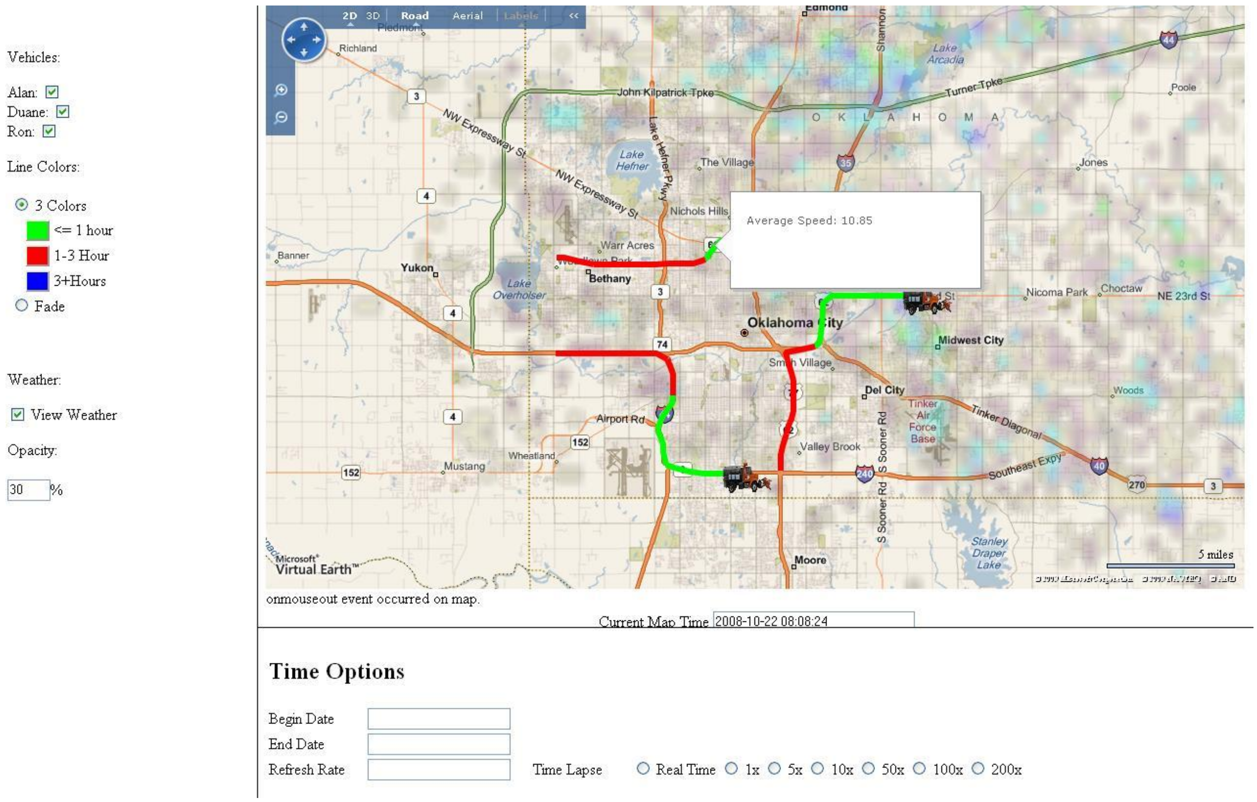


Figure 11: Control of the display of information on the Inclement Weather Console (left) and the simulated replay of stored historical data (bottom).

Weather readings from RWIS stations are correlated with AVL information as well as with vehicle speeds taken from Remote Traffic Microwave Sensors. This correlation is the first step in the formulation of decision support systems that can improve the effectiveness of the treatment of road surfaces and the routing of weather response vehicles. Additionally, similar systems can inform the traveling public regarding weather-impacted travel times and can thereby increase the likelihood of safe travelling decisions.

Figure 12 shows an alternative view of the IWC which is more focused on the display of information from information from Oklahoma Mesonet and Oklahoma City Micronet stations. In this view, each available station is displayed as a blue triangle. Hovering over one of the stations causes a mouseover popup to appear which displays the name, temperature, wind speed, wind direction, and collection time for the station. Historical details for the station can be obtained by clicking on the station icon. When the station icon is clicked, a graph is displayed to the right of the map showing recent trends in temperature data. The exact historical temperatures and their associated timestamps are also shown beneath the temperature graph.

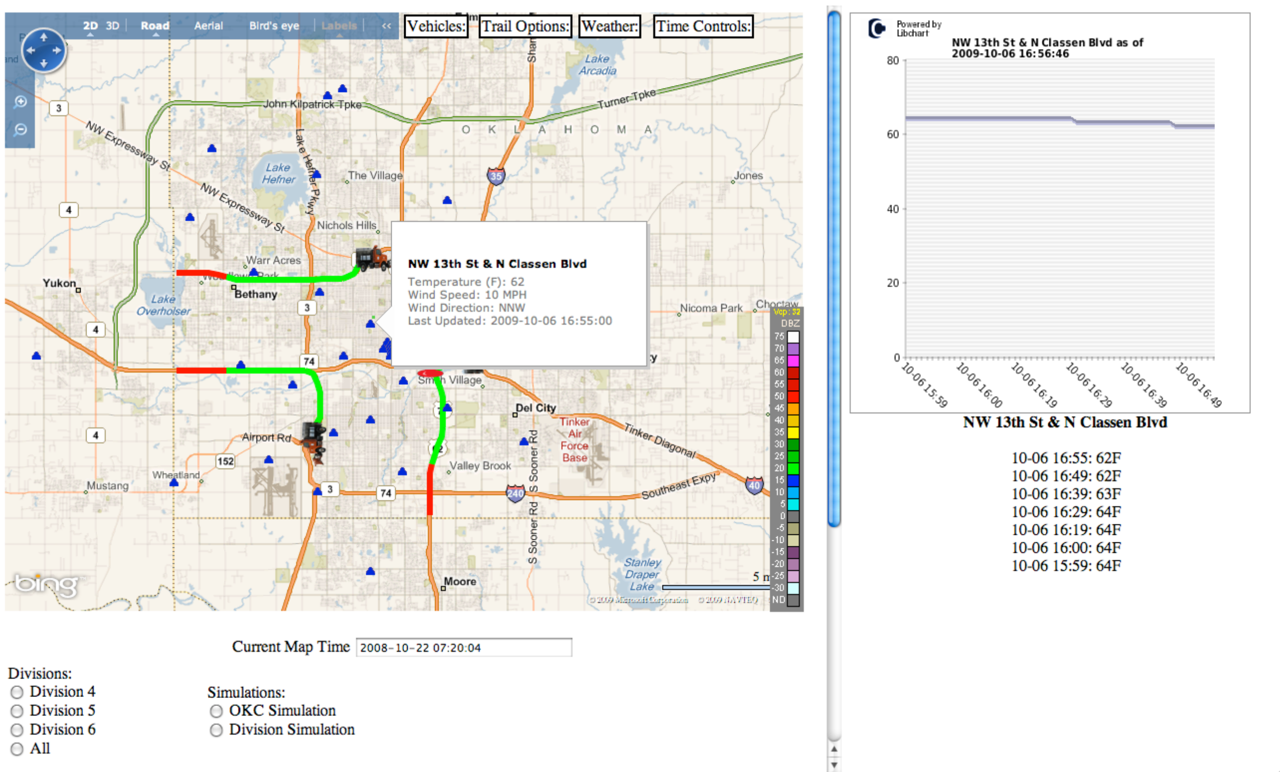


Figure 12: Display of Mesonet and Micronet weather station data on the Inclement Weather Console.

The view of the IWC shown in Figure 13 is similar to that of Figure 12 in that it contains a dedicated frame which displays information based on user interaction with the map. Rather than weather station data, however, the dedicated frame in Figure 13 displays detailed information for an individual salt truck. When the user clicks the icon for a salt truck on the map, the frame to the right of the map is refreshed to display several details for that salt truck, including total miles driven, total air blasts used, the number of miles driven while dispersing a sand/salt mixture, the number of miles driven while dispersing Magnesium Chloride, the number of miles driven with the plow up, and the number of miles driven with the plow down. This frame in conjunction with the interactive map can be used by an IWC operator to very efficiently observe the status of deployed salt trucks. In addition, the map in Figure 13 displays an excellent example of overlayed weather data images. By directly observing weather radar data as it relates to deployed salt trucks, IWC operators can remain fully apprised of current conditions for the salt trucks. IWC operators can then make educated and efficient decisions regarding further deployment of the trucks.

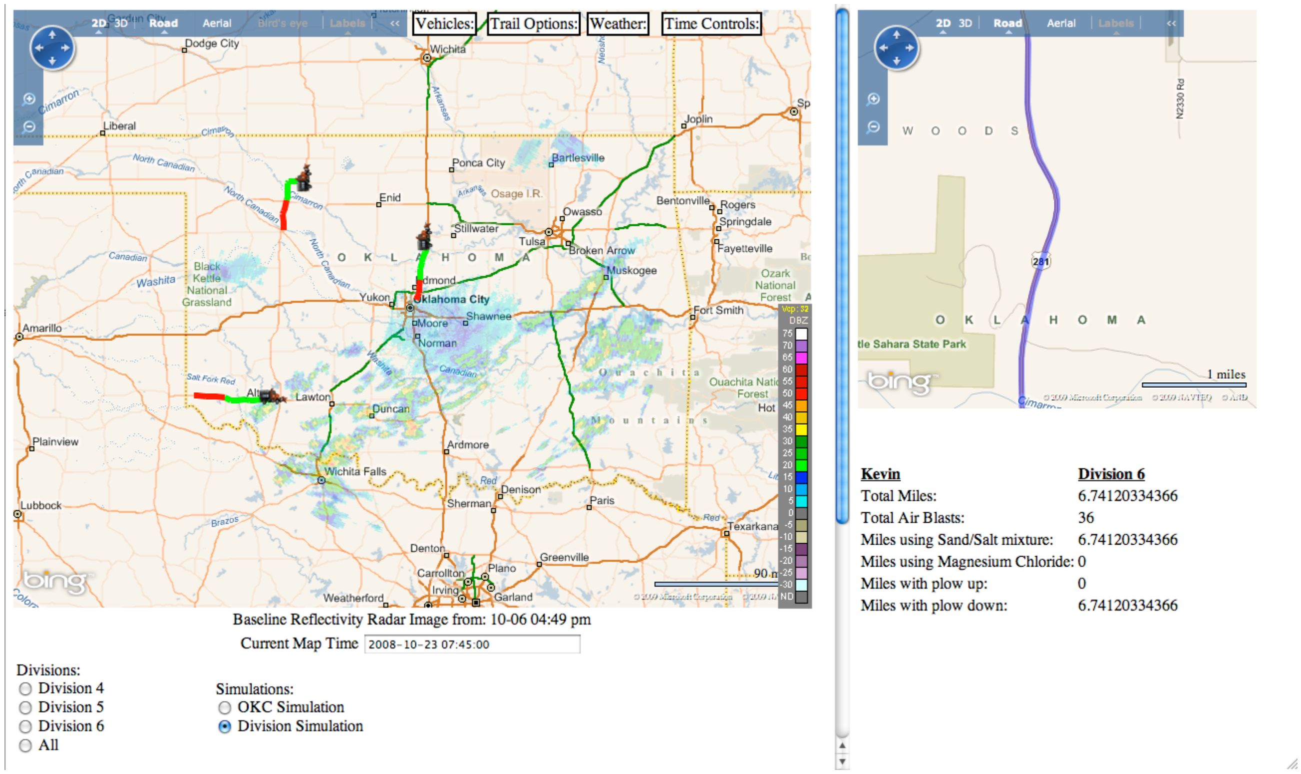


Figure 13: Display of individual salt truck status on the Inclement Weather Console.

Also located at the bottom of Figure 12 and Figure 13 are *Division* and *Simulation* options. The Division options allow the IWC operator to only view salt trucks from selected Divisions. This can help reduce map clutter and information overload, particularly if historical trails are being displayed for several trucks. The Simulation options can be used to display stored salt truck route and usage data in the IWC. These options are used for demonstration purposes and assist in displaying the potential of the IWC.

3.4 Automatic Vehicle Tracking

Many vehicle-specific opportunities exist for sensing various characteristic of the tracked vehicle and reporting that back to our system both to be visualized and to be utilized in decision support.

Various aspects that comprise the status of the vehicle have been considered for instrumentation:

1. The condition of plow (degree up or down)
2. The content and quantity of the deicing agent payload
3. The mix ratio of deicing agents currently being applied
4. The current spread rate of deicing agent application

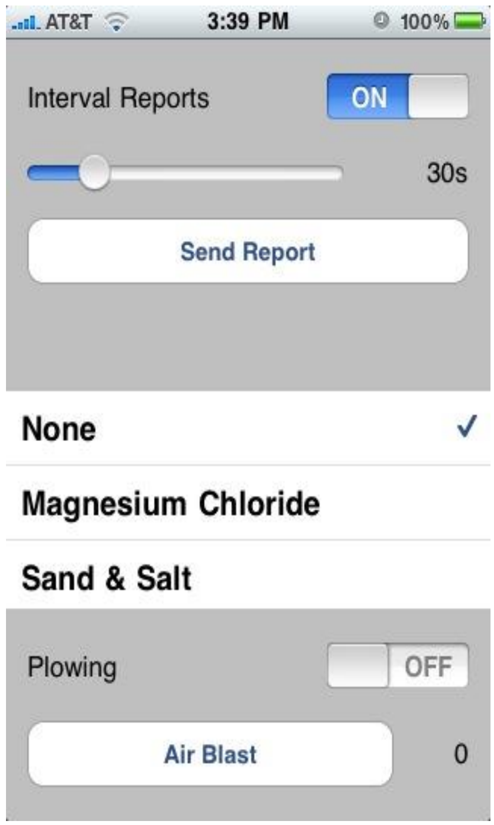


Figure 14: iPhone application used to simulate instrumented vehicles.

Instruments for these various measurements are, by necessity, custom to the vehicle being instrumented. The vehicles that are desirable to track during inclement weather consist of different types of vehicles (including plows and spreader trucks) with a variety of makes of each type. Additionally, many features will be missing from particular vehicles. For example, some trucks may not feature a movable plow, and some spreader vehicles always apply the same mix of salts and sand at the same rate.

Our initial study of vehicle instrumentation was simulated using custom-written mobile phone applications. We chose to develop two different mobile phone apps, an iPhone application and a java application based on the current BlackBerry. The first instrumentation simulation platform we developed was for the iPhone. The iPhone was chosen as the first platform as several members already had iPhones, which allowed us to rapidly and immediately begin developing an iPhone prototype while we waited for development iPhone and BlackBerry devices to be procured. The final iPhone application is shown in Figure 14. The interface provides automated reporting based an interval set by the user using a slide bar. It also provides a button to manually send a report, the ability to choose which type of mixture is being deployed (the options are retrieved from the web server), a switch to designate the plow as up or down, and the ability to count the number of air blasts performed during a reporting interval. The initial testing based on the iPhone was a success. We were able to simulate and display a vehicle as it drove from north OKC to south OKC while sending data at regular intervals. Unfortunately there were some phone limitations that proved problematic, most notably the inability to run the application in the background and the phones inability to maintain a GPS lock, resulting in "approximate" locations being sent using cell phone tower triangulation rather than actual GPS coordinates.

A second similar instrumentation platform was developed for the Blackberry mobile device. This application was developed for the Java subsystem made available by the Blackberry. Based on Java, this application is more robust and portable to other Java enabled cell phones/devices making it a more practical platform.

Figure 15: AVL device model GPSI-3900

Figure 16: Dashboard control panel of instrumented snowplow

In addition to the mobile phone platforms developed for prototyping and testing the AVL functionality, we further integrated our system to accept data from AVL devices that were provided by a vendor GPS Insight for testing. The device we installed, the GPSI-3900 is shown in Figure 15. This device transmits not only its location, but also the status of several closed contact switches. In our deployment, these switches control the plow. The control panel of one of snowplows we instrumented is shown in Figure 16. In this image, the GPSI-3900 is connected to the vehicle electrical system and the control panel for the plow so that the status of the plow can be monitored.

Automated Vehicle Location Data

Treatment methods for the mitigation of inclement weather effects on transportation systems fall into two categories: chemical and mechanical. The application of sodium chloride and other chemical de-icing and anti-icing agents is effective in both preventing icing conditions and reducing their effects, but have a number of adverse effects on the environment and the infrastructure itself [23]. Mechanical treatments such as snow plowing also cause infrastructure damage through repetitive physical strikes of the plow with equipment embedded in pavement surfaces such as reflectors and lane markings as well as the pavement material itself. Maximizing treatment effectiveness, minimizing unnecessary resource usage, and maximizing application efficiency are primary objectives of the transportation officials charged with directing the application of these measures. These objectives necessitate that decision makers not only have the capability to monitor roadway conditions, but they must also maintain visibility of treatment actions and their effectiveness.

In support of these efforts the Laboratory has developed a system of data structures, interfaces, and software utilities to facilitate the transmission, storage, and display of real-time treatment application information. The following sections detail the primary motives, use cases, and processes involved in the development of these components. Together they support milestones 2, 3, 4, 5, 7, and 10.

Data Structures

Providing real-time and historical treatment data requires that the structure designed to chronicle their application correlate five (5) key elements: who, what, where, when, and how. When combined, these elements associate the resources being used with a specific time and location. The ITS Laboratory designed the Automated Vehicle Locator (AVL) data repository to store these five elements in a structured report containing eight (8) data fields: A unique treatment report identifier, a treatment applicator resource identifier, the geographical latitude of the treated region, the geographical longitude of the treated region, the date and time of treatment, the type of chemical treatment applied if applicable, and the type of mechanical treatment applied if applicable. To maintain a minimally complicated data structure and avoid data errors, these reports are stored individually and are not associated with each other in this structure.

ODOT currently uses a fairly limited set of chemicals for treatment, but market influence, resource availability, and future regulation may require changes in chemical treatment methods. Also if equipped with more than one treatment option, many applicators provide the driver with the ability to choose which chemical or combination of chemicals to dispense. Each of the potentially applied chemicals and combinations thereof is denoted in the AVL data structures by an arbitrarily assigned, uniquely representative, numerical identifier coupled with a human readable, modifiable, textual description of the chemical composition or combination. To maintain the simplified report structure described above, this numerical identifier is used to denote any chemical treatments applied to a region.

Since it is inevitable that not all treatment equipment will have identical capabilities, the ability to account for heterogeneous sets of equipment and their individual ability is necessary. This accounting is accomplished through a classification of treatment applicator resources we call the applicator's vehicle type. Vehicle type is denoted by an arbitrarily assigned, uniquely representative, numerical identifier coupled with a human readable, modifiable, textual description of the equipment and a textual representation of its capabilities. Because the scope of the project did not include investigation into the full range of capabilities at the disposal of ODOT and the agencies supporting them during inclement weather, the data structure's capability tracking field was made intentionally generic to account for an extremely wide variety of equipment.

Interfaces

The commoditization of wireless networking through cellular systems in recent years has made communication to mobile devices faster, easier, and cheaper than ever. The infrastructure required to maintain active data connections with low power devices on unlicensed bands is expanded every day benefiting from the economies of scale stemming from an ever increasing user base. As the technologies these systems use mature and newer, more efficient, network standards evolve, these consumer networks only stand to increase their ubiquity. The wide availability of commercial-off-the-shelf equipment capable of connecting to consumer networks decreases the overhead of deploying remote devices to State agencies as well as to external entities. Finally, cellular networks in the United States provide their users with a connection to the wider Internet, providing immense flexibility in the deployment and load balancing of the centralized data collection services. It is for these reasons we decided the AVL system should utilize consumer wireless data networks instead of slower, less flexible, licensed radio networks, such as those currently deployed by ODOT to a subset of its vehicle fleet.

With a varied set of potential remote devices, it is not possible to design a single internet facing service to which any device from any vendor can connect and successfully transmit data. Industry standard mechanisms do exist for service discovery and definition but the overhead in handling such mechanisms in a mobile, embedded reporting device requires a sizable increase in the cost of the remote hardware. Furthermore these standards require a greater volume of network data transmission which often increases the cost of the network service. We decided a compromise between industry standards and a proprietary data format would suit our goals for both simplicity of implementation as well as minimization of network traffic and remote hardware. To this end we developed a simple XML schema that defines data formats to be used in the transmission of location reports from remote devices to our service as well as the format in which applicator resources, applicator classifications, and potentially dispensed chemical combinations may be transmitted from the service. This specification can be found in Appendix A.

Once actual hardware was deployed, an additional process was developed to support the collection and storage of instrumentation data from the device. The particular device chosen for deployment is not capable of directly creating a link to our service and instead can only connect to a service provided by the device's vendor. To facilitate the transfer of this instrumentation data to our service, we developed a process that constantly checks for and harvests data from the vendor's website. When new data becomes available, it is actively and seamlessly added to our data collection and presented as if the device were directly interfaced to our service.

Software Utilities

Until remote monitoring hardware is fully deployed to treatment applicator resources and actual events occur that require the utilization of those resources, no real data could be collected for demonstrations needed to support the iterative, rapid application development model used on this project. The time required for such hardware deployment, however, combined with infrequent occurrences of inclement weather during the contract period motivated the development of synthetic data generators. The two primary methods developed for this data generation were the import of GPS tracks from offline historical recordings and real time collection of GPS tracks from network enabled mobile platforms.

Historical tracks mapping paths taken by applicator resources in previous inclement weather events were obtained from ODOT, but without instrumentation only limited data was included. These tracks do not contain applicator information beyond their location in time, however they do provide data sets where multiple resources are simultaneously active in a specific geographical region. These sets are useful in simulating visualizations that include multiple resources. Additionally they inherently provide travel paths that are realistic and reasonable to assume will be similar to tracks followed in future resource employments.

Providing real time instrumentation data providing empirical insight into realistic, unpredictable circumstances such as network signal interruption, inaccuracy and imprecision during GPS signal distortion, and report inconsistencies requires actual hardware deployment and experimentation. To minimize time-to-deployment and maximize usability of such a solution, we exploited mobile phone hardware already in use by Laboratory members and our contract monitors. This required only that we augment these devices--capable of GPS location and internet communication--with customized software designed to collect information and communicate with our web service. During this work the most prevalent mobile phone platforms in the United States were Apple's iPhone and Research in Motion's Blackberry [24], so an application for each of these two platforms was developed.

Both of the applications developed used information from the GPS equipped units for location readings and supplanted treatment application data with parameters set manually on their user interfaces. The applications request from the web service which chemicals would be available for dispersement on an actual applicator resource and displays a selectable list on the screen. Other user selectable options included the status of potential physical mitigation techniques, temporary increases in chemical application, and report generation and transmission intervals. Also, provisions enabling the user to force a report transmission were provided. Figure 14 shows the user interface shown on an Apple iPhone platform. The mobile phone data generator proved useful for both demonstrating live AVL data reporting as well as mimicking the potential shortfalls of various hardware solutions.

3.5 Display in ATIS

RWIS weather data, along with still images from the webcameras that are part of each RWIS deployment are also provided to a page on Oklahoma's Advanced Traveler Information System (ATIS). The Oklahoma ATIS, shown in Figure 17, is a website that acts as an information portal for data gathered from ITS devices along Oklahoma roadways. A few other states, such as North and South Dakota are already providing weather condition information derived from RWIS stations to the public via 511 and ATIS [11].

The Oklahoma ATIS is a useful tool for traffic engineers in the state, and the RWIS data provides an additional layer of information for them. It is an integral component of the Oklahoma ITS network. While many states have large Traffic Management Centers (TMC), in Oklahoma a decision was made to decentralize the TMC in order to make it accessible to stakeholders from around the state. Decentralization of the TMC has also resulted in substantial cost savings and improved fault tolerance. The decentralized TMC was realized by creating a private dual-ring network on a fiber-optic backbone. This private ITS network is used to connect Oklahoma ITS devices and controlling stations called *ITS Consoles*. Each ITS Console has the capability to monitor and control any ITS device that is visible to it, including pan/tilt/zoom analog cameras, digital webcameras, Dynamic Message Signs (DMS), and Remote Traffic Microwave Sensor (RTMS) speed detectors.

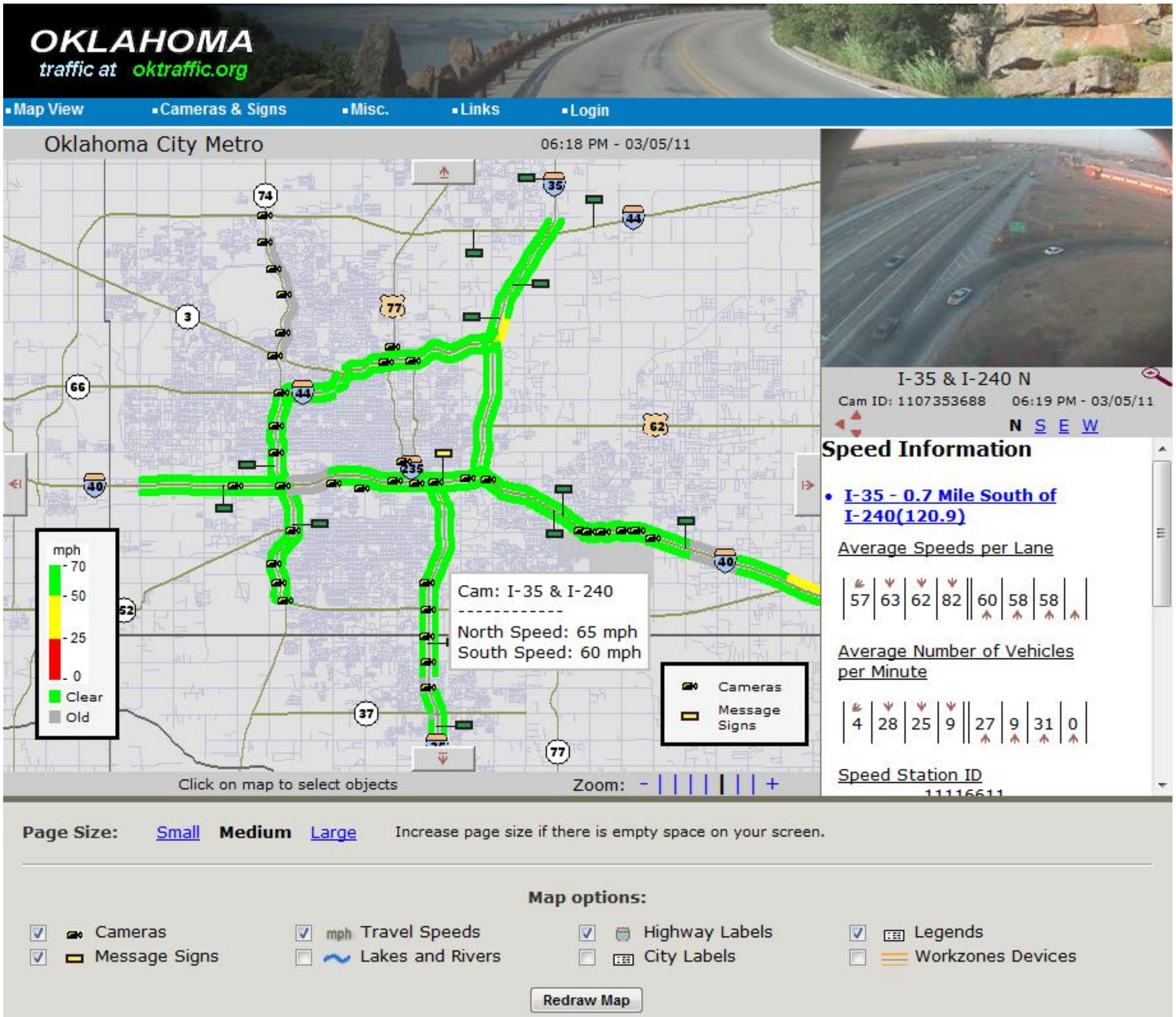
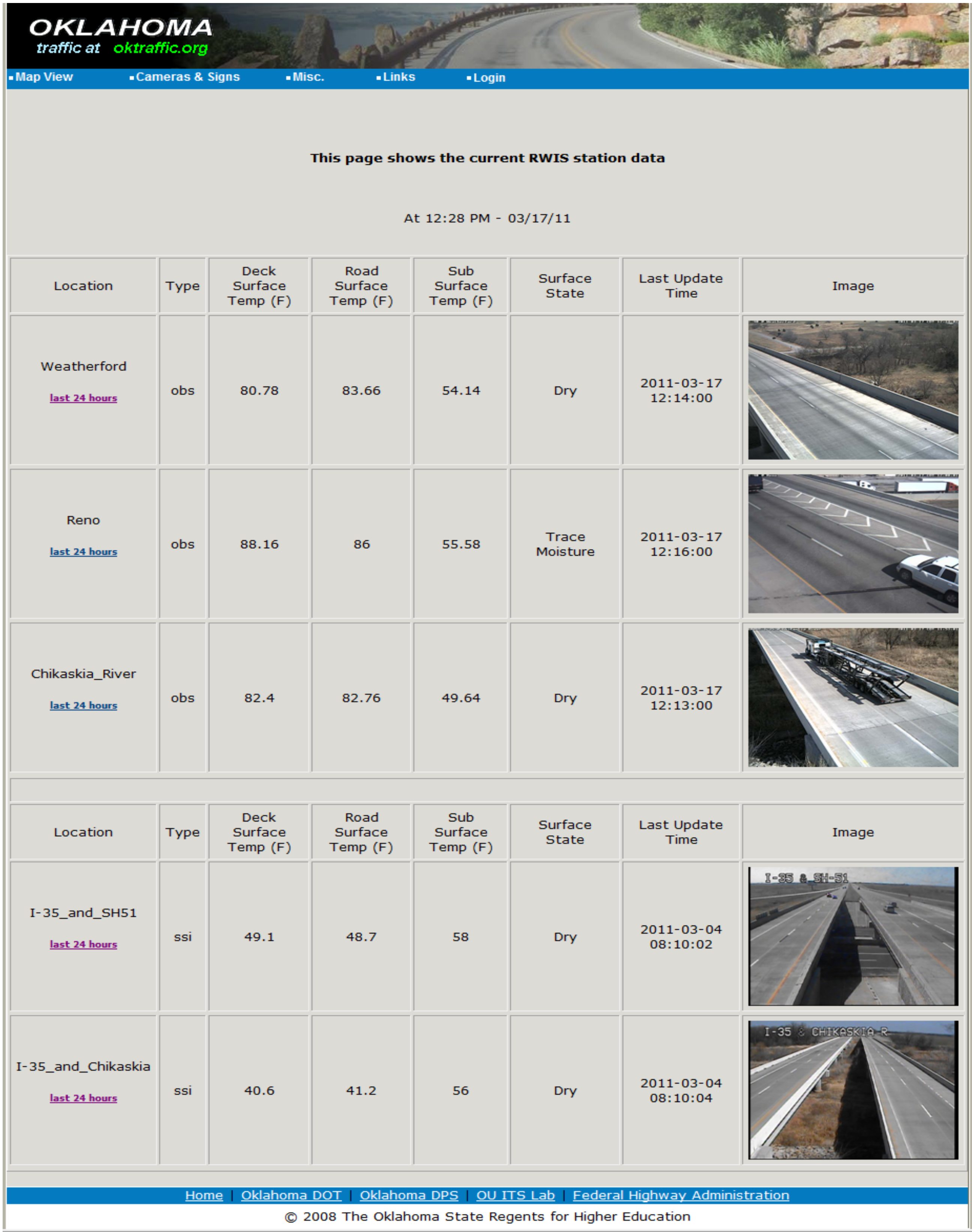


Figure 17: Screen shot of the map page on Oklahoma's ATIS website

Though the ITS network is a private, secure network, information from the network is displayed on the internet via the Oklahoma ATIS. This provides an important information service for Oklahoma travelers, allowing them to make informed choices regarding route finding and traffic avoidance based on current traffic conditions. In addition to information from the private network, the ATIS also gathers and displays information provided from third-party sources. This information includes speed data from Traffic.com, smart workzone device data from construction companies, and data obtained from RWIS stations. As such, the ATIS forms an important gateway between the private ITS network and the public internet. The server hosting the ATIS, known as the ATIS server, provides data from public internet sources to the ITS consoles on the private network and provides data from the private network to the general public.

Not all information gathered by the ATIS server is made available to the general public. For example, Traffic.com provides ODOT with speed data for each lane on a highway, but by-lane speeds cannot be disseminated to the general public as that would conflict with the business interests of Traffic.com. Therefore, the speed information given to the general public on the ATIS website is limited to average speeds across all lanes in a given direction. By-lane speed data, however, can be very useful to ODOT engineers who use the ATIS website, and so it is desirable to display this data. This issue was resolved by creating and maintaining both a public and private version of the ATIS website. The private version requires a password to access and displays all available information and features. The public version of the website is an exact copy of the private version with limited access to information and features. This arrangement also provides an important test-bed for new website functionality as features can be tested by several users on the private side before being unlocked on the public side.

As the collection of RWIS station data is still a pilot project, the pages within the ATIS displaying RWIS data are limited to the private version of the ATIS. The question of how RWIS data should best be disseminated to the traveling public is a difficult one [25]. The main RWIS page (accessible only through the private interface to ATIS), shown in Figure 18, displays RWIS data from all available RWIS stations. This data includes the station location, vendor, deck surface temperature, road surface temperature, surface condition, sensor timestamp and current image. The page is organized to show all Vaisala stations in the server database followed by all SSI stations. The data shown is the latest data successfully collected via the Vaisala and SSI collection scripts running on the server.



OKLAHOMA
traffic at oktraffic.org

▪Map View ▪Cameras & Signs ▪Misc. ▪Links ▪Login

This page shows the current RWIS station data

At 12:28 PM - 03/17/11

Location	Type	Deck Surface Temp (F)	Road Surface Temp (F)	Sub Surface Temp (F)	Surface State	Last Update Time	Image
Weatherford last 24 hours	obs	80.78	83.66	54.14	Dry	2011-03-17 12:14:00	
Reno last 24 hours	obs	88.16	86	55.58	Trace Moisture	2011-03-17 12:16:00	
Chikaskia_River last 24 hours	obs	82.4	82.76	49.64	Dry	2011-03-17 12:13:00	

Location	Type	Deck Surface Temp (F)	Road Surface Temp (F)	Sub Surface Temp (F)	Surface State	Last Update Time	Image
I-35_and_SH51 last 24 hours	ssi	49.1	48.7	58	Dry	2011-03-04 08:10:02	
I-35_and_Chikaskia last 24 hours	ssi	40.6	41.2	56	Dry	2011-03-04 08:10:04	

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Figure 18: Screen shot of the RWIS summary page on Oklahoma's ATIS website.

The RWIS page in the ATIS utilizes the PHP programming language to query the server database and automatically generate a page displaying all data found for current RWIS stations. The page first searches the *weather_stations* table in the database for available Vaisala stations. The page then queries the *weather_values* table to obtain the latest weather station data gathered from the stations. The data for each station is then presented as a row in a table on the page. The image shown in the rightmost cell of the row is the *image_filename* stored in the latest *weather_values* table entry for the station.

After a small break on the page, the process is repeated for all available SSI stations. The latest data from each station is obtained from the *ssi_values* table. For both vendor types, the columns of the data tables are matched to the generic table headings shown on the page.

The display of the images on the RWIS page is accomplished using PHP scripts designed to retrieve the images. All images displayed on the page are stored in the *images* directory on the server as described in Section 0, which is not a directory that is available to the public internet. The directory itself is hidden from the public internet to prevent other sites or applications from directly linking to images hosted on the ATIS. The images are served to ATIS users through a *show_img* script that retrieves requested image data and transmits it to the viewer. The *show_img* script is capable of retrieving image data from several different image repositories on the server, and in the case of RWIS images, the RWIS page passes a special variable to the *show_img* script. This variable instructs the script to obtain the requested image from the *images* directory and also bypasses restrictions that normally prevent the display of images that are over an hour old.

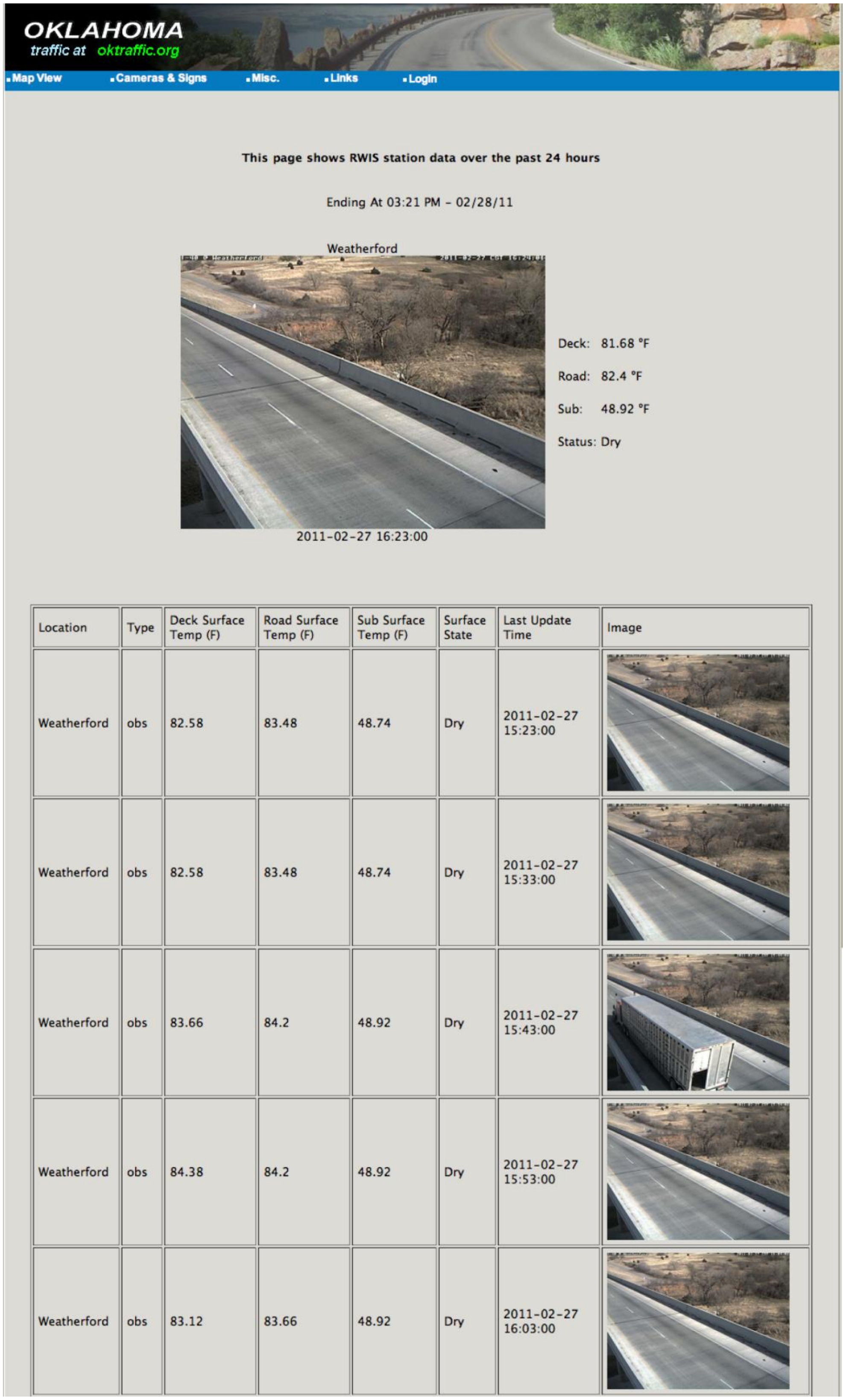
Each station on the RWIS page also includes a link that can be used to go to a 24 hour view of station. This view is displayed to the user as a new page, but uses the same PHP script of the main page. This is accomplished through the use of a *stationID* parameter that can be passed to the PHP script that generates the pages. If no *stationID* parameter is passed to the script, the main RWIS page displaying all available RWIS stations is generated. If a *stationID* parameter is passed to the script, then a page is generated which displays all weather data obtained from the specified station within the previous 24 hours.

The page displaying historical weather data for a specific station lists all weather readings for the station in the same table format that is used for the main RWIS page. In addition, the historical weather data page includes a large image at the top of the page that shows a time-lapse loop of the available images from the station. Changing times, temperatures, and statuses that correspond to the changing images are also displayed next to the time-lapse loop. Since the RWIS data collection scripts are run every 10 minutes, this structure results in a time-lapse loop displaying the past 24-hours of readings in 10 minute time steps. This loop can be used to very quickly view recent weather changes at the location, while the table beneath the loop allows the user to see the weather changes in detail. Figure 19 shows the historical weather data page for the RWIS station along I-40 near Weatherford.

All recorded historical weather data is stored in the *weather_values* and *ssi_values* tables in the server database. The historical weather data page generates a time-lapse loop and table from the stored data by first querying the *weather_stations* table to determine the vendor type of the RWIS station that has been specified for the page. The page then obtains all data readings in the previous 24 hours from the *weather_values* table if the specified station was a Vaisala station or from the *ssi_values* table if the specified sation was an SSI station.

These data readings are then used to automatically generate JavaScript code that drives the time-lapse loop. The JavaScript functions that were developed to implement the time-lapse loop operate by first filling the time-lapse loop image and corresponding text readings with the first available data readings obtained. The JavaScript functions then replace the time-lapse loop image and text readings with subsequent data readings at regular intervals. When the latest data readings are displayed, the JavaScript functions pause the loop briefly before restarting the loop with the first available data readings.

The images displayed in both the time-lapse loop and table on the historical weather data page utilize the same *show_img* script used in the main RWIS page.


OKLAHOMA
traffic at oktraffic.org

Map View | Cameras & Signs | Misc. | Links | Login

This page shows RWIS station data over the past 24 hours

Ending At 03:21 PM - 02/28/11

Weatherford

Deck: 81.68 °F

Road: 82.4 °F

Sub: 48.92 °F

Status: Dry

2011-02-27 16:23:00

Location	Type	Deck Surface Temp (F)	Road Surface Temp (F)	Sub Surface Temp (F)	Surface State	Last Update Time	Image
Weatherford	obs	82.58	83.48	48.74	Dry	2011-02-27 15:23:00	
Weatherford	obs	82.58	83.48	48.74	Dry	2011-02-27 15:33:00	
Weatherford	obs	83.66	84.2	48.92	Dry	2011-02-27 15:43:00	
Weatherford	obs	84.38	84.2	48.92	Dry	2011-02-27 15:53:00	
Weatherford	obs	83.12	83.66	48.92	Dry	2011-02-27 16:03:00	

Figure 19: Screen shot of the 24-hour log of sensor readings and images from one of the deployed RWIS stations.

The RWIS section of the Oklahoma ATIS contributes meaningfully to the information conveyed by the site as a whole. The RWIS weather data and images provide an additional layer of roadway information that is not available from most of the ITS devices deployed in the state. Perhaps most importantly, the RWIS stations act as independent sensor locations that can be placed anywhere in the state. The majority of Oklahoma ITS roadway devices have been placed in the Oklahoma City and Tulsa metro areas. Many of the RWIS stations that have been deployed were placed in locations that are far away from the metro areas and thus provide traffic engineers with the only up-to-date information available from the far reaches of the state. Taken as a whole, the RWIS sensor readings provide traffic engineers with a comprehensive view of statewide road conditions.

3.6 Weather Related Traffic Flow Analysis

Data from RWIS stations, combined with GIS can be used as a powerful decision support tool for planning response to inclement weather [26]. Data from RWIS stations can be used along with thermodynamic models to predict roadway icing under various conditions such as the time of day [27]. Without this type of system, managers must rely on weather forecasts and measurements that are not necessarily well related to the actual pavement conditions. With Decision Support Systems (DSS) built on the technology deployed in this project, engineers can use actual pavement conditions. These real-time conditions can also be used by automated processes such as automatic bridge spraying equipment that being used in North Dakota to reduce crashes and by complex algorithms (e.g., evolutionary genetic algorithm) for scheduling weather response [28]. Additionally, any predictions made in the DSS can also be made based on these actual conditions rather than other predictions.

Another key input to effective DSS is traffic-flow analysis. This analysis is a vital component of this project. Combined with correlatatable data on traffic flow, RWIS sensor data allows transportation engineers to follow best practices [28] prioritizing efficient and effective response to areas most vulnerable to weather-related traffic collisions under the observed circumstances.

The major design considerations for the weather related traffic flow analysis were the network infrastructures, the collection and warehousing of data, and the methods by which the data would be analyzed and used for key decisions. ODOT and the OU ITS lab have been collecting traffic flow data from RTMS since 2004, but the techniques to analyze and visualize this data had not been developed until this project began.

The data itself becomes sizable considering that speed, volume and occupancy measurements are recorded every minute for up to six lanes at 77 RTMS sensors. A plot of two data points from an approximately nine month period can be seen in Figure 20. Analysis of this figure shows that there are two major traffic *modes* free-flow and congested. Free flow traffic is represented by the large concentration of data points in the rectangle 0-33 Veh./Min by 55-80 MPH. Congested traffic is in the data from 5-30 Veh./Min. by 0-20 MPH. There is a noticeable traffic-phase transition between the two modes in the range of 20-30 Veh./Min. and 20-55 MPH. Statistical techniques such as k-means, fuzzy c-means, and means-shift confirm the interpretation that there genuinely two modes [29,30,31].

Primary research into traffic flow was necessitated by the shear quantity of exploitable data input into this system. The integration of RTMS traffic flow data allows the traffic engineer to exploit more traffic flow data per single lane per year than is contained in the sum total of the academic literature data excluding [2]. Roadway systems in the US have been increasingly instrumented through public only sensor investments as well as public/private joint ventures. These new sensor networks generate significantly more data at greater detail than can be obtained from previous sensor technologies. The developments of the IWC are allowing traffic engineers to have an unprecedented ease of understanding of these large data sets.

In Oklahoma RTMS sensors are located along major arterials in the Oklahoma City and Tulsa metropolitan areas. RTMS data generally is lane specific with many lanes in Oklahoma rarely experiencing congested traffic during normal weather conditions. As one may expect lanes experience higher congestion near the intersection of two major arterials. The algorithms and techniques to do per-lane analysis with simple visualizations as well as the implementation statistical analysis tools to estimate the underlying flow plane distribution. Techniques that have been developed but not fully integrated into the IWC would:

1) Automate the data analysis by lane excluding on/off-ramps using means-shift or similar Bayesian classification technology. This will result in one or two major traffic modes.

2) Estimate the first and second moments the data points associated with each of the mode(s) referenced in (1) above.

3) Use these as Bayesian classifiers to determine when traffic is in free/congested or in an abnormal traffic state.

Correlating this data with weather data has shown some promise and would be of the greatest benefit to the current project [32]. Unfortunately this weather data has not been archived by ODOT and alternate sources of the historical record of this data is not cost effective or readily available. With the installation of RWIS stations and the integration of NOAA, OCS, and NWS data sources this data analysis can begin in earnest for Oklahoma.

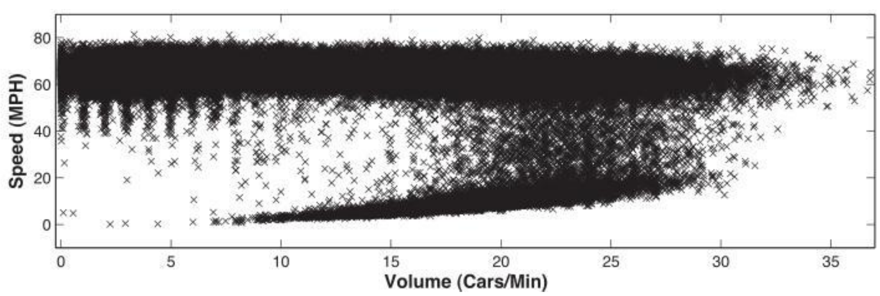


Figure 20: Flow-plane Plot (104k data-points with congested traffic)

An open-source database solution, MySQL, is being used for data storage because it is both low cost and easy to maintain. A significant consideration is that the volume of data coming from NWS forecasts is untenable for a small research and engineering operation requiring a large expenditure in data storage equipment. Three things are required for weather data correlation to traffic flow:

1. An operational definition of inclement weather must be adopted such that some small representation of data can be used to indicate weather at a given traffic location (generally tied to the location of sensors in the network). For example if a threshold is set for what is considered inclement weather due to liquid precipitation then only one bit is required to store that information.

Having several types of inclement weather then only requires a small additional storage requirement.

2. An ability to parse data from data feed into a centralized format. Since RWIS, NWS and the OCS assets all transmit data in different data formats, a general data parser and input mechanism is required.

3. The ability to spatially correlate weather data with traffic sensor locations. The NWS' National Digital Forecast Database (NDFD) via Simple Object Access Protocol (SOAP) will do this correlation easily. Transmit a list of lat./long. via SOAP to receive a list of forecasts for those locations. NWS forecasts are updated hourly while traffic flow data is acquired every minute. Although weather forecasts are fairly accurate on these time scales, it does not represent the *actual weather conditions* on the roadway being observed by the sensor.

RWIS and OCS assets do provide *actual weather conditions* at a given location but each have some considerations for the traffic engineer. Studies have shown actual weather condition data to be more useful in statistical analysis to aid in decision making for application of deicing materials [33]. In simulated models, a finite difference algorithm, BridgeT, has modeled the vertical heat transfer in bridges based on similar real-time weather conditions in order to better estimate icing and frost conditions on bridges [34] [35] (a particular hazard when the occurs in patches where the adjacent roadways are clear of frost). However, correlating data points from RWIS stations and the OCS weather station requires more work on the part of the traffic engineer. OCS assets are removed from major roadways to avoid radiant heating effects since the primary focus of OCS is weather science.

As an example where RWIS data has been used in conjunction with other real-time weather data, the impact of rain data on crash probabilities has been studied using a combination of RWIS and surface weather stations [36]. Most of the roads studied did not have RWIS data available and so records from weather stations near the roads were used instead. However, rain data was demonstrated to accurately predict conditions that increase crashes. Wide deployment and use of RWIS in Oklahoma thus can improve highway safety. While Oklahoma's current RWIS configuration is relatively sparse, the RWIS weather stations that are already deployed have the advantage over stations deployed for meteorological purposes of being spatially local to the roadway, give real time data about current road surface conditions, and are controlled as direct assets of traffic engineers. While the weather/traffic correlation in Oklahoma is still in its early stages, we have provided a robust data analysis infrastructure through the process of this project.

Data visualization technologies were also evaluated during the process of this project. Future inclement weather visualization techniques will allow the traffic engineer an easy way to digest the important features of this large body of data. Changing the representation of the data in Figure 20 to be represented with time can be seen in Figure 21. The main thrust of this research in this line is to extend our current technologies to be integrated into the IWC.

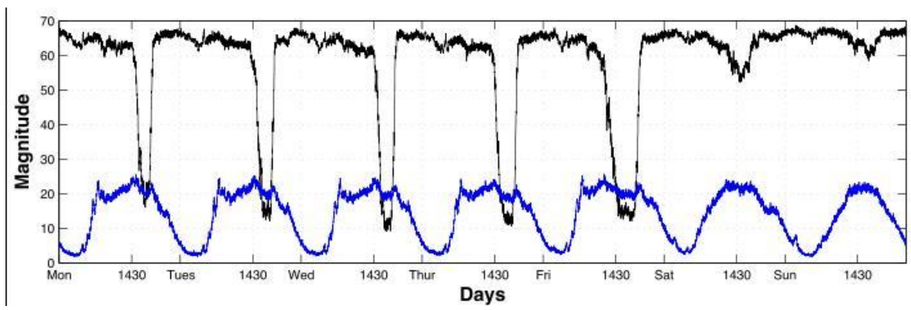


Figure 21: One Week Mean Traffic Flow

The figures presented in this section were generated using a proprietary software suite that is not open-source. However, several open-source solutions were investigated for suitability to be integrated in future versions of the IWC. There are several no-cost solutions available to visualize data in the .Net community but since they are generally not very mature and do not have full time development teams this software often does not have the robust feature set that one might desire for a fully functional visualization system. The freeware package gnuplot [37], on the contrary, has a long history and a mature feature set. One of the major detractors of gnuplot is that it requires more time on the part of the developer to integrate into a software suite such as the IWC. Since there are several applications of the data analysis process related as this project progresses several data visualization are needed to fully understand data representation. Currently, data from RWIS stations is available via the IWC's GIS interface and allows the user to directly read data from the selected RWIS as well as displays the current weather trend using .Net plotting software allowing the user to have an understanding of recent weather development. There is also a radar overlay feature which in itself represents a significant data resource for the short term weather picture.

Future work in this direction would be to allow the integration of data analysis and weather correlation into the IWC. Allowing the traffic engineer to customize the data-analysis processes through a web interface and manage the resulting data visualizations seems highly desirable.
The last key component of this part of the DSS is the statistical analysis tools that are required for data analysis. Many of these tools will need to be developed from scratch though there are some software packages available for data analysis tools. Price point is also an important consideration when considering data analysis tools. Matlab™ is an excellent all around solution to both data analysis and visualization. Operations of this software package can be automated and scripted using Matlab's innate scripting language or using the commonly used programming languages C, C++ or Fortran and then compiling them into Matlab usable files via the Matlab provided compiler mex. Compiling files using mex requires that the developer familiarize themselves with many structures that are required for the data transfer between the compiled code and the Matlab process which can be burdensome and require additional over-head. However, this time loss consideration must be balanced with the fact that Matlab is robust and mature and comes with a suite of high-level data analysis tools the replication of most is not required in by the software developer. Depending on the complexity of the operations required for analysis Matlab is a viable option at with costs ranging from $2,000 for the software package with no statistical support to $12,000 for a fully functional statistical support software per license for government use.

There are many programming language based software analysis kits that are not written at as high a level as an environment such as Matlab. An exhaustive list would be infeasible here. One such package and one of the least costly option (free) is the GNU Scientific Library (GSL) which is less robustly featured than Matlab. GSL has a smaller set of statistical functions than many of the more costly packages and does not incorporate changes in statistical analysis tools as quickly as some of them. So for some of the sophisticated or newly developed statistical analysis techniques there is a labor and research requirement on the part of the developer. GSL is a set of libraries that can be used by various programming languages such as C, C++, C#, fortran, perl, php … etc. There is no native data visualization package though integrating the file formats required to generate plot via gnuplot would alleviate the lack of plotting functionality. From OU ITS' experience the installation and use of GSL is relatively easy for server-side application when compared to other analysis toolsets. Another consideration is that GSL has a long history of support and is unlikely to be dropped from the maintenance cycle.

In addition to visualization and appropriate analysis tools, effective use of the available data will require the development of training programs [38] to help engineers use the information to better make decisions regarding chemical types, application rates, and proper plowing techniques.

3.7 Project Accomplishments

This project, "Roadway Weather Information System and Automatic Vehicle Location Coordination," has met of the deliverables proposed for the contract. We have developed an IWC integrating vehicle location data and instrumentation as well as various weather sensors from both ODOT and Mesonet. We have assisted in the deployment of RWIS stations for ODOT. We have developed a preliminary instrumentation platform to test our overall system design. Through a demonstrated port of ATIS to the Microsoft Bing Maps platform, we have also further developed support to display complete RWIS weather information to the public ATIS along with as additional weather information sources such as NOAA weather radar and Mesonet and Micronet weather readings. Of course, the use of this data in the public ATIS requires authorization from the respective sources.

The inclusion of RWIS data in the Oklahoma ATIS has also raised the potential for this technology to be of use to the general public. Although the work done in this pilot project is not yet mature enough to warrant dissemination of RWIS data to the general public, the RWIS data already displayed on the private version of the ATIS has shown that it can be used to monitor roadway conditions around the state. Such information would be invaluable to travelers on Oklahoma interstates, as specific information about roadway conditions in rural parts of the state is currently unavailable. In particular, the weather information from the RWIS stations would greatly assist interstate travelers who are attempting to avoid adverse weather conditions.

If RWIS data were to be made available to the general public, it would reach a sizable audience.

Figure 22 shows the Site Hits page displayed on the private version of the ATIS. This page details visitor traffic to the site, including numbers for both overall site hits and unique IP addresses that visited the site. The site hits give an indication of server load while the unique IP addresses give a measure of unique visitors to the site. The page itself makes use of timelines provided by Google Visualizations to present a quick overview of site usage

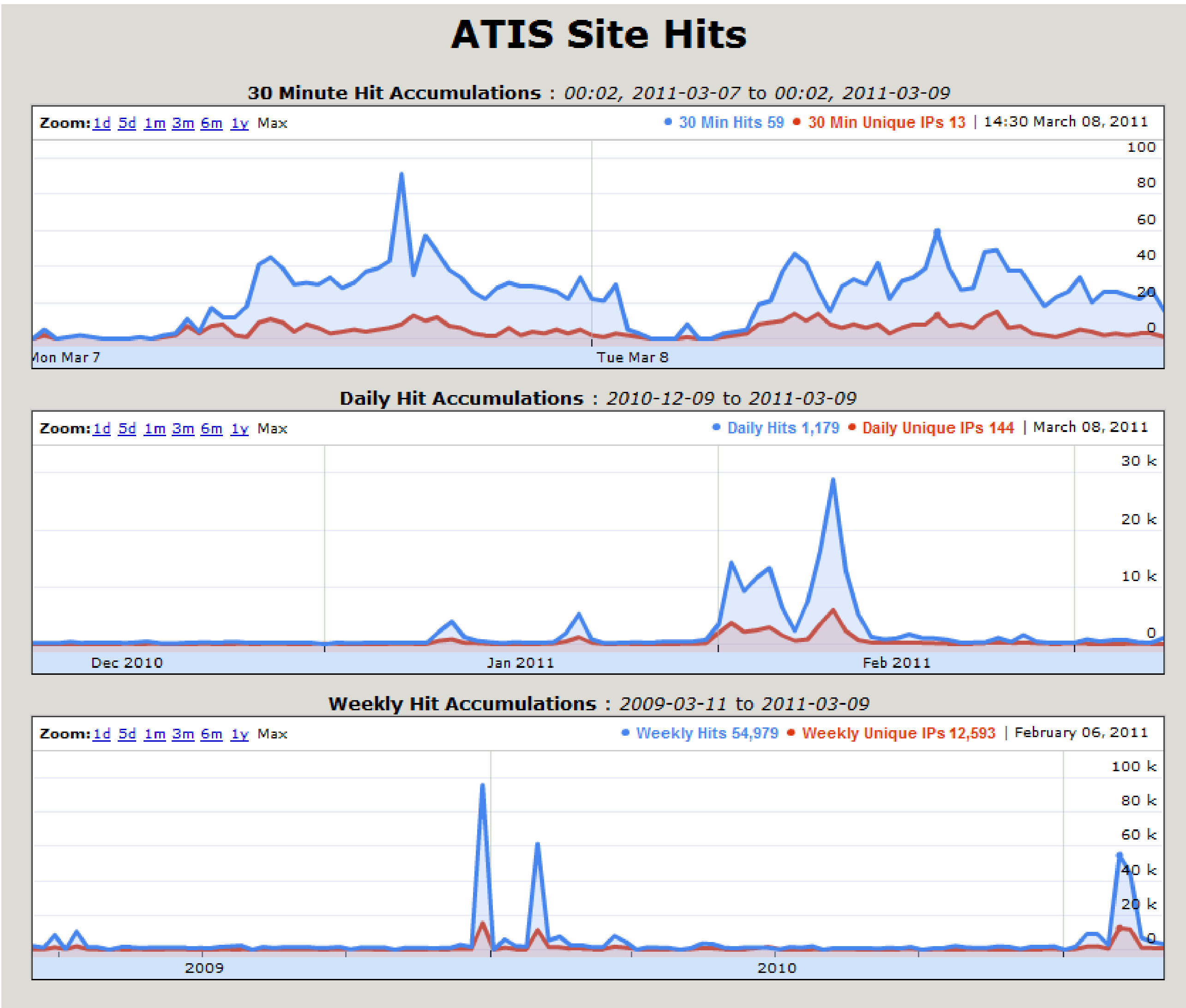


Figure 22: History of site hits for Oklahoma's ATIS website

The Site Hits page displays three separate timelines that graph visitor traffic counted at thirty minute, one day, and one week intervals. The thirty minute interval graph is useful for observing fluctuations over a couple of days, while the one day and one week graphs are useful for observing changes in visitor traffic over longer periods. As can be seen in Figure 22, the Oklahoma ATIS experiences considerable variations in visitor traffic. In a typical day the site sees roughly one to two hundred visitors, with most visitors viewing the site during daylight hours and with slight spikes in traffic in the morning and afternoon hours. Large spikes can be seen, however, in the timelines over longer periods, with traffic reaching two to five thousand visitors on some days. These days correspond to time periods during which large ice storms moved through Oklahoma, resulting in a greatly increased demand among the general public for information about traffic conditions.

An additional likely contributing factor to the large numbers of site hits during winter storms is the mention of the Oklahoma ATIS in local state media at the time of the storms. During the storms, the websites of Oklahoma City television networks contained links to the Oklahoma ATIS, which likely led to a large number of the site hits seen. The ATIS has also recently seen the implementation of streaming camera feeds, which has resulted in local television networks mentioning the ATIS during news segments. This has also likely resulted in increased site traffic. As the user base for the ATIS grows, the potential impact of RWIS data that is given to that user base also becomes greater.

4. Conclusions and Impact

Through the prototype IWC we have provided decision makers with a system that will improve transportation safety through efficient response to inclement weather conditions on highways and bridges. This impact will increase as information from this system is provided to the public to enhance their ability to make safe travel decisions. Now that this platform is available a platform for decision support system research as well as research into areas such as intelligent travel time prediction and routing, we anticipate increased opportunities for publication and for attracting additional sources of funding for further development of the IWC.

During the winter of 2009-2010, we collected end-user feedback on the Inclement Weather Console and its Decision Support features at that time. The console was made available to ODOT planners and decision makers for this testing purpose and weather sensor readings and limited vehicle data was stored for further analysis and review. This pilot provided an opportunity to evaluate the system under non-synthetic conditions and the feedback received led to numerous improvements.

The activities of this project centered on the creation of polled data feeds for weather sensor and AVL position readings, a database to store these readings and a geographic based visualization using Microsoft Visual Earth. To facilitate the collection of weather sensor data, we assisted with the deployment of 6 RWIS stations. However, the roll out of ODOT's network of RWIS stations is a lengthy process and even future stations, once deployed, will be relatively sparsely arranged along Oklahoma's Interstate highways. For this reason, we utilized data streams from the Oklahoma Mesonet [3] and the Oklahoma City Micronet [5] to provide a more immediate and comprehensive observation of statewide weather. In the future, models developed at the Oklahoma Climetological Survey [39], may enable the interpolation of pavement and bridge conditions where there are no RWIS stations located. Advances in climatological research have made it possible to improve the ability to use micro and local climate information in predicting and giving warnings about weather related roadway hazards. These advances are being leveraged to improve the performance and significance of modern RWIS's [40]. Similarly, data from external weather measurement are also being used by ODOT to further be used to validate sensor readings taken at RWIS sites [41].

In addition to assisting with the RWIS deployment, we also developed mobile phone tracking applications and instrumented snowplows with trial AVL equipment for vehicle location and status collection and visualization.

In the course of this project, we developed an aggregate approach to traffic flow prediction that generates a prediction from one or more component predictors [2]. These feed-forward neural network predictors combine temporally local information with the predicted mean value estimated from a limited set of historic data. We are using this aggregate approach to combine RWIS sensor data with Remote Traffic Microwave Sensor (RTMS) readings. The aggregate traffic flow information is utilized to form better travel-time predictions that are able to adapt not only to traffic congestion because of peak commute-times and accidents, but also to weather events including rain and snow that impact travel time. Once validated, these travel time can be communicated to motorists via dynamic message signs on interstates and highways as well as through the ATIS site.

Through the Oklahoma Advanced Traveler Information System (ATIS) [42], ODOT currently provides travelers with real-time information about Oklahoma's Interstates and other highways. This information is currently limited to still images and video loops from cameras deployed along highways in Oklahoma metropolitan areas. The ability to monitor current road conditions can soon be enhanced by providing traffic speed information and travel time predictions, as well as the ability to monitor Smart Work Zones. Once the RWIS stations are more fully deployed and validated, we can enable for the general public, the integrated view of weather-related road conditions with the currently provided traffic conditions through this ATIS website. By presenting this integrated outlook, the ATIS/RWIS site will further inform traveler's decisions. The weather data will likely be a critical piece of information provided to travelers through the ATIS site to improve safety through improved traveler decisions (including the decision not to travel) and improved routing. Additionally, the improved statewide travel-time prediction described will further increase the usefulness of the travel-time system providing information to travelers via the ATIS website and Dynamic Message Signs. The improved routing through the state will be particularly useful for interstate commercial vehicle traffic. In addition to wider use of Oklahoma's ATIS, as IWC is put to greater use, we are confident that significant benefits will be achieved in terms of increased traveler safety, in increased effectiveness of the response to poor road conditions and in terms of cost avoidance through optimization of the use of resources in inclement conditions.

5. References Cited

[1] A.J. Khattak and K.K. Knapp, "Snow event effects on interstate highway crashes," *J. Cold Regions Engineering*, vol. 15, no. 4, pp. 219-229, Dec. 2001.

[2] J.R. Junger, J.P. Havlicek, R.D. Barnes, and M.P. Tull, "Prediction aggregation of remote traffic microwave sensors speed and volume data," in *Intelligent Transportation Systems, 2009. ITSC '09. 12th International IEEE Conference on*, 4-7 Oct. 2009, pp. 1-6.

[3] Oklahoma Mesonet. (2011, February) Mesonet. [Online]. http://www.Mesonet.org/

[4] R. A. McPherson et al., "Statewide Monitoring of the Mesoscale Environment: A Technical Update on the Oklahoma Mesonet," *Journal of Atmospheric and Oceanic Technology*, vol. 24, no. 3, pp. 301-321.

[5] Oklahoma City Mesonet. (2011, February) Oklahoma City Mesonet. [Online]. http://okc.Mesonet.org/

[6] D.E. Herzmann, W.A. Gallus, and B.R. Temeyer D.P. Todey, "An inter-comparison of RWIS data with AWOS and ASOS data in the State of Iowa," in *Proc. Int'l. Conf. Interactive Information, Process. Syst. for Meteorology, Oceanography, and Hydrology, Amer. Meteorological Society*, Orlando, FL, Jan. 2002, pp. 150-152.

[8] J.P. Koermer, W.L. Real, and S.W. Gray B. Hoch, "Implementation of RWIS in New Hampshire," in *Proc. AMS Annual Meeting, American Meteorological Society*, Atlanta, GA, Jan. 2006.

[7] J.P. Koermer, W.L. Real, and S.W. Gray B. Hoch, "Usage of RWIS in New Hampshire for monitoring environmental and pavement," in *Proc. AMS Annual Meeting, American Meteorological Society*, San Antonio, TX, Jan. 2007.

[9] E. Ryden, "What is RWIS?," *Roads and Bridges*, vol. 36, no. 12, pp. 30-31, Dec. 1998.

[10] D. Burkheimer, "Iowa DOT stalks roadway weather," *Roads and Bridges*, vol. 39, no. 9, pp. 29-31, Sep. 2001.

[11] R. Southerland, "RWIS eliminates guesswork," *American City and County*, vol. 116, no. 6, pp. 4-6, Apr. 15 2001.

[12] T.J. Martinelli and M.J. Adams, "Climate control," *Civil Engineering*, vol. 68, no. 8, pp. 62-64, Aug. 1998.

[13] T. McClellan, "Alphabet soup," *Road and Bridges*, vol. 46, no. 10, pp. 28-31, Oct. 2008.

[14] R. Shapard, and T. Black J. Ward, "From blacktop to desktop: five technologies changing public works," *American City and County*, vol. 112, no. 10, pp. 33-50, Sep. 1997.

[15] C. Haas, J. Weissmann, and R. Greer B. McKeever, "Life cycle cost-benefit model for road weather information systems," *Transportation Research Record*, vol. 1627, no. 1, pp. 41-48, Jan. 1998.

[16] Inc. Vaisala, "Pavement condition sensors," *Roads and Bridges*, vol. 48, no. 6, p. 56, Jun. 2010.

[18] A. Amanna and A. Schroeder, "Serial wireless IP networks for DOT applications," in *Proc. IEEE Intell. Transportation Syst. Conf.*, Washington, DC, Oct. 3-6, 2004, pp. 274-279.

[17] M. Eriksson and J. Norrman, "Analysis of station locations in road weather information system," *Meteorol. Appl.*, vol. 8, no. 4, pp. 437-448, Dec. 2001.

[19] National Transportation Communications for ITS Protocol. (2011, February) Welcome to NTCIP. [Online]. http://www.ntcip.org/

[20] Google.com. (2011, February) Google Earth. [Online]. http://earth.google.com

[21] Google.com. (2011, February) Google Maps. [Online]. http://maps.google.com/

[22] Microsoft Bing Maps. (2011, February) Bing Maps. [Online]. http://www.bing.com/maps/

[23] Transportation Research Board National Research Council. (1991) Highway Deicing: Comparing Salt and Calcium Magnesium Acetate. Special Report 235. [Online]. http://onlinepubs.trb.org/onlinepubs/sr/sr235.html

[24] (2011, March) Nielsen's New App Playbook Debunks Mobile App Store Myth. [Online]. http://blog.nielsen.com/nielsenwire/wp-content/uploads/2010/03/trended-app-store.png

[25] P. Martin, H. Perrin, and D. Meldrum B. Hansen, "Delivering road weather information to the traveling public," *Transportation Research Record*, vol. 1745, no. 1, pp. 46-52, Jan. 2001.

[26] R. Hanneman, "Chipping away," *American City and County*, vol. 121, no. 4, pp. 36-38, Apr. 2006.

[28] D. Veneziano, Z. Ye, D. Williams, and X. Shi L. Fay, "Costs and benefits of tools to maintain winter roads," *Transportation Research Record*, vol. 2169, no. 1, pp. 174-186, Dec. 2010.

[27] P. Delannoy, and S. Allan E.G. Siegel, "A potent formula: model calculates potential for ice-covered roads," *Roads and Bridges*, vol. 49, no. 2, pp. 52-55, Feb. 2011.

[29] Yuan Yueming and Wei Guan, "Empirical studies of unblocked index for urban freeway traffic flow states," in *Intelligent Transportation Systems, 12th International IEEE Conference on*, 4-7 Oct. 2009, pp. 1-6.

[30] Hui-Zhe Zhang, Hong Chen, and Li-Xia Bao, "An improved Fuzzy C Means clustering algorithm and its application in traffic condition recognition," in *Fuzzy Systems and Knowledge Discovery (FSKD), 2010 Seventh International Conference on*, vol. 4, 10-12 Aug. 2010, pp. 1608-1612.

[31] Jian-Mei Xiao and Xi-Huai Wang, "Study on traffic flow prediction using RBF neural network," in *Machine Learning and Cybernetics, 2004. Proceedings of 2004 International Conference on*, vol. 5, 26-29 Aug. 2004, pp. 2672- 2675.

[32] Mohamed A. Abdel-Aty and Rajashekar Pemmanaboina, "Calibrating a Real-Time Traffic Crash-Prediction Model Using Archived Weather and ITS Traffic Data," *IEEE Transactions on Intelligent Transportation Systems*, vol. 7, no. 2, June 2006.

[33] A. Sherif and Y. Hassan, "Modelling of pavement temperature for winter maintenance operations," *Canadian J. Civil Engin.*, vol. 31, no. 2, pp. 369-378, Apr. 2004.

[34] T.M. Greenfield and E.S. Takle, "Bridge frost prediction by heat and mass transfer methods," *J. Applied Meteorology, Climatology*, vol. 45, no. 3, pp. 517-525, Mar. 2006.

[35] E.S. Takle, W.A. Gallus, D. Burkheimer, and D. McCauley D.S. Knollhoff, "A model for forecasting frost accumulation on bridge decks based on RWIS data," in *Proc. Int'l. Conf. Interactive Information, Process. Syst. for Meteorology, Oceanography, and Hydrology, Amer. Meteorological Society*, Albuquerque, NM, Jan. 2001, pp. 279-281.

[36] M.A. Abdel-Aty and R. Pemmanaboina, "Calibrating a real-time traffic crash-prediction model using archived weather and ITS traffic data," *IEEE Trans. Intell. Transportation Syst.*, vol. 7, no. 2, pp. 167-174, Jun. 2006.

[38] W.S. Larson, "Hand over fist," *Roads and Bridges*, vol. 45, no. 4, pp. 30-37, Apr. 2007.

[37] Gnuplot. (2011, February) gnuplot homepage. [Online]. http://www.gnuplot.info/

[39] J. M. Rathke and R. A. McPherson, "Modeling road pavement temperatures with skin temperature observations from the Oklahoma Mesonet," in *23rd Conference on Interactive Info. Processing Systems*, 2007.

[40] T. Gustavsson and J. Bogren, "Information not data: future development of road weather information systems," *Geografiska Annaler Series A: Physical Geography*, vol. 89, no. 4, pp. 263-271, Dec. 2007.

[41] L. F. Osborne and M. Askelson J. Hanson, "Road weather sensor data validation," in *23rd Conference on Interactive Info. Processing Systems*, 2007.

[42] Oklahoma ATIS. (February, 2011) Oklahoma Advanced Traveler Information System. [Online]. http://www.oktraffic.org/

[43] P. Pisano, "Heavy accumulation," *Roads and Bridges*, vol. 42, no. 7, pp. 33-43, Jul. 2004.

[44] D. Pyde, "One fleet for 1 bridge," *Roads and Bridges*, vol. 44, no. 4, pp. 42-43, Apr. 2005.

[45] L. Chapman, and X. Yao H. Handa, "Robust route optimization for gritting/salting trucks: a CERCIA experience," *IEEE Computational Intell. Mag.*, vol. 1, no. 1, pp. 6-9, Feb. 2006.

[46] P. Delannoy, and D. Denault A. Koonar, "Building a road weather information network for integrating data from heterogeneous sources," in *Proc. 3rd Int'l. Conf. Information Tech., Appl.*, Sydney, Australia, Jul 4-7, 2005, pp. 501-507.

6. Appendix A - AVL Data Exchange XML Schema

```xml
<?xml version="1.0" encoding="utf-8"?>
<s:schema
    targetNamespace="http://oktraffic.org/rwis/salt_points.xsd"
    xmlns="http://oktraffic.org/rwis/salt_points.xsd"
    xmlns:s="http://www.w3.org/2001/XMLSchema">

  <!--General Purpose Field-->
  <s:complexType name="DataElement">
    <s:simpleContent>
      <!--SQL descriptor of database restrictions on the information stored by
       this field-->
      <s:extension base="s:string">
        <!--Field value-->
        <s:attribute name="Type" type="s:string"/>
      </s:extension>
    </s:simpleContent>
  </s:complexType>

  <!--GPS Location and truck status reporting-->
  <s:complexType name="SaltPointReport">
    <s:all>
      <!--The human readable identifier denoting which vehicle is sending this
       report-->
      <s:element minOccurs="1" maxOccurs="1" name="truckID" type="s:string"/>

      <!--The longitude at which the report was generated codified in -180 to
       180 degrees (to the most accurate/precise variable decimal possible) where
       values less than 0 represent locations in the Western Hemisphere, and
       those greater than 0, the Eastern-->
      <s:element minOccurs="1" maxOccurs="1" name="longitude" type="s:float"/>

      <!--The latitude at which the report was generated codified in -180 to 180
       degrees (to the most accurate/precise variable decimal possible) where
       values less than 0 represent locations in the Southern Hemisphere, and
       those greater than 0, the Noprthern-->
      <s:element minOccurs="1" maxOccurs="1" name="latitude" type="s:float"/>

      <!--The time at which the report was generated (the end of the reporting
       period)-->
      <s:element minOccurs="1" maxOccurs="1" name="dt" type="s:dateTime"/>

      <!--The system identifier for any chemical being applied over the
       reporting period-->
      <s:element minOccurs="1" maxOccurs="1" name="chemical_type_id"
type="s:unsignedInt"/>

      <!--A true/false value denoting whether the vehicle's plow device was
       engaged over the reporting period-->
      <s:element minOccurs="1" maxOccurs="1" name="plow_down" type="s:boolean"/>

      <!--A count of times the vehicle's driver issued a "blast" command to the
       chemical dispensing system, indicating the need for more application and
       also an increase in application-->
      <s:element minOccurs="1" maxOccurs="1" name="blast_count"
type="s:unsignedInt"/>
    </s:all>
  </s:complexType>

  <s:complexType name="ListOfSaltPoints">
    <s:sequence>
      <s:element minOccurs="0" maxOccurs="unbounded" type="SaltPointReport"
```

```
name="Report"/>
    </s:sequence>
  </s:complexType>

  <s:element type="ListOfSaltPoints" name="Salt_Points"/>

  <!--Vehicle Listing-->
  <s:complexType name="SingleVehicle">
    <s:all>
      <!--The internal system identifer for a single vehicle-->
      <s:element minOccurs="1" maxOccurs="1" name="VehID" type="DataElement"/>

      <!--The system identifier for the type of vehicle that will be sending
       reports-->
      <s:element minOccurs="1" maxOccurs="1" name="TypeID" type="DataElement"/>

      <!--A human readable short description of the vehicle that will typically
       appear when human distinction between vehicles is required-->
      <s:element minOccurs="1" maxOccurs="1" name="vehName" type="DataElement"/>

      <!--An identifer used to distinguish a vehicle's parent organization-->
      <s:element minOccurs="1" maxOccurs="1" name="DivID" type="DataElement"/>
    </s:all>
  </s:complexType>

  <s:complexType name="ListOfVehicles">
    <s:sequence>
      <s:element minOccurs="0" maxOccurs="unbounded" name="Vehicle"
type="SingleVehicle"/>
    </s:sequence>
  </s:complexType>

  <s:element type="ListOfVehicles" name="Vehicles"/>

  <!--Potential Chemical Application Listing-->
  <s:complexType name="SingleChemical">
    <s:all>
      <!--This element's content is an identifier that should be used in a
       Report/chemical_type_id element to identify the chemical being applied at
       the time of the location report-->
      <s:element minOccurs="1" maxOccurs="1" name="id" type="DataElement"/>
      <!--This element's content is a human readable descriptor of the chemical
       denoted by the ID paired with it-->
      <s:element minOccurs="1" maxOccurs="1" name="type" type="DataElement"/>
    </s:all>
  </s:complexType>

  <s:complexType name="ListOfChemicals">
    <s:sequence>
      <s:element minOccurs="0" maxOccurs="unbounded" name="Chemical"
type="SingleChemical"/>
    </s:sequence>
  </s:complexType>

  <s:element type="ListOfChemicals" name="chemical_type"/>

  <!--Potential Vehicle Type Listing-->
  <s:complexType name="SingleVehicleType">
    <s:all>
      <!--The system identifier related to -->
      <s:element type="DataElement" name="TypeID"/>

      <!--A human readable descriptive of the type of vehicle represented by
       this type: ex. Truck-->
```

```
      <s:element type="DataElement" name="Type"/>

      <!--A boolean value specifying whether the vehicle type possess chemical
       dispensing capabilities-->
      <s:element type="DataElement" name="Salt"/>
    </s:all>
  </s:complexType>

  <s:complexType name="ListOfVehicleTypes">
    <s:sequence>
      <s:element minOccurs="0" maxOccurs="unbounded" name="VehType"
type="SingleVehicleType"/>
    </s:sequence>
  </s:complexType>

  <s:element type="ListOfVehicleTypes" name="VehTypes"/>

</s:schema>
```