OKLAHOMA TRANSPORTATION CENTER

ECONOMIC ENHANCEMENT THROUGH INFRASTRUCTURE STEWARDSHIP

A MOBILE INTELLIGENT TRANSPORTATION SYSTEM (ITS) PLATFORM

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16. ABSTRACT

In this project we developed and purchased new Mobile Intelligent Transportation (M-ITS) assets to improve the data collection and traffic engineering capabilities in Oklahoma. The focus of the developed platform was for use in locations where deploying permanent assets, such pole-mounted cameras and radars would be cost prohibitive for the duration of their use. The M-ITS was successfully developed and integrated with the existing Oklahoma Department of Transportation (ODOT) statewide network of cameras, radars and dynamic message signs. Major improvements to the data collection and mobile information systems were added to OU Intelligent Transportation Laboratory (ITS) and its role of supporting the Oklahoma Department of Transportation in its mission to improve safety and throughput of Oklahoma's roads. The improvements focused on a variety of aspects of transportation from custom weather sensor and mobile real-time traffic monitoring to hardening existing ITS infrastructure to ensure network stability in the event of a disaster. Post contract activity has already demonstrated the usefulness of these systems not only in routine special projects but in disaster recovery. Major improvements to the capability of the OU Intelligent Transportation Laboratory (ITS) were made. This system has and continues to make a significant positive impact on the transportation systems in the state of Oklahoma and integrates well into the ODOT network.

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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		
in^2	square inches	645.2	square millimeters	mm
ft^2	square feet	0.0929	square meters	m^2
yd^2	square yards	0.8361	square meters	m^2
ac	acres	0.4047	hectares	ha
mi^2	square miles	2.590	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0283	cubic meters	m^3
yd^3	cubic yards	0.7645	cubic meters	m^3
		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/in^2	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		
mm^2	square millimeters	0.00155	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectares	2.471	acres	ac
km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME		
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallons	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
		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/in^2

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The authors express their appreciation to the Oklahoma Transportation Center (OkTC) for their support of this project. We would also like to thank the Oklahoma Climatological Survey. We would also like to thank the Oklahoma Department of Transportation (ODOT) for the resources they have committed to the project, particularly in design and integrations phases of this project.

A Mobile Intelligent Transportation System (ITS) Platform

Final Report

7/6/2013

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Executive Summary

Traffic engineers, municipal planners, and emergency responders have a critical need for rapidly deployable roadway systems to gather, analyze, and disseminate information to the travelling public. Traffic researchers need mobile and temporarily located assets to understand underlying traffic flow patterns to identify and model traffic information. In many situations the deployment of fixed assets, such as concrete structures and metal poles is cost prohibitive for the duration of intended use. Emergency managers require rapidly deployable self-contained information gathering and disseminating systems to operate in environments where support infrastructure is unavailable. Mobile Intelligent Transportation Systems (M-ITS) fulfill these needs by developing deployable trailers, cameras, signs, and the equipment required to deploy these assets in the field.

In Oklahoma traffic systems are managed by the Oklahoma Department of Transportation (ODOT), which develops and maintains a growing network of roadside intelligent systems. The ODOT network is maintained and developed by ITS. An incomplete list of the central elements of the ODOT network is networking hardware, dynamic message signs (DMS), remote traffic microwave sensors, power and support systems, data analysis programs, and data storage elements. Specifically OU ITS has added Traffic/Weather Observation Trailers, Dynamic Message Sign Trailers, Speed Sensor Trailers, a Chevrolet Tahoe, a Ford F250 Extended Cab, Generator Backup Systems for Data Servers, Climate Control for Servers, Additional Server Assets, Additional Data Storage Assets, and Ruggedized Computing Equipment.

The enhanced capabilities the systems developed in this project provide will be important to a wide range to traffic and safety stakeholders. In fact, the assets from this project and the capabilities they have added to OU ITS have already had a significant impact. Included in this report are two case studies outlining the use of these systems in the field after the completion of this project that meet the objectives of this project.

Chapter 1

1.1. Introduction

Transportation information infrastructure development tends to concentrate in major metropolitan areas where it can have the greatest impact on the traveling public and motor carriers. Such information networks also tend to rely on the proximity of utilities and communication networks. In situations where that infrastructure is temporarily unavailable, such as a natural disaster, or in a rural environment, there are vital applications for Mobile Intelligent Transportation Systems (M-ITS). In Oklahoma, some portable assets exist for deployment at temporary construction and road improvement project sites. These are in addition to the fixed location assets of the Oklahoma Intelligent Transportation System, see Figure 1, Figure 2, and Figure 3. Existing, mobile systems usually only capture a limited amount of information, traffic speed and volume, and are maintained by third party vendors. These systems are also not available to the OU ITS Laboratory for rapid deployment.

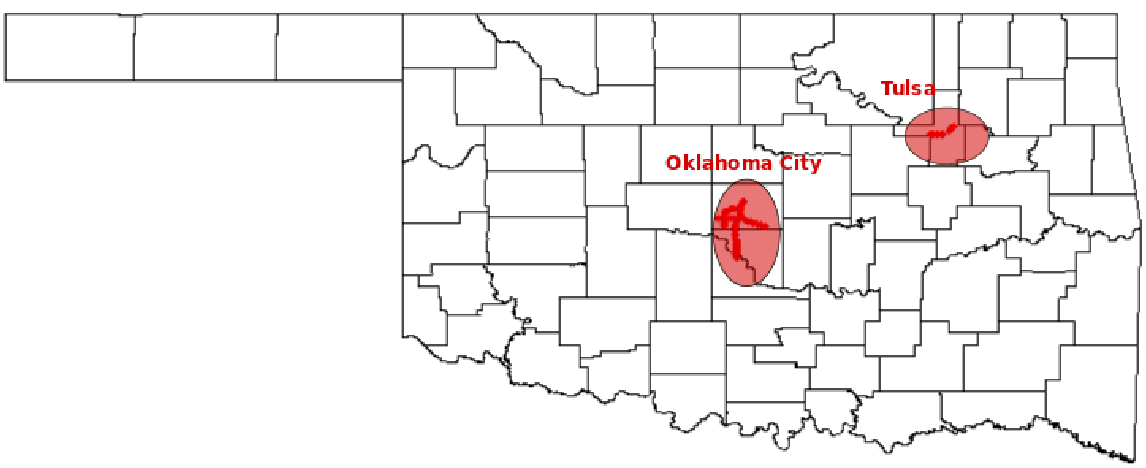

Figure 1: Location of Pole Mounted Remote Microwave Traffic Sensor

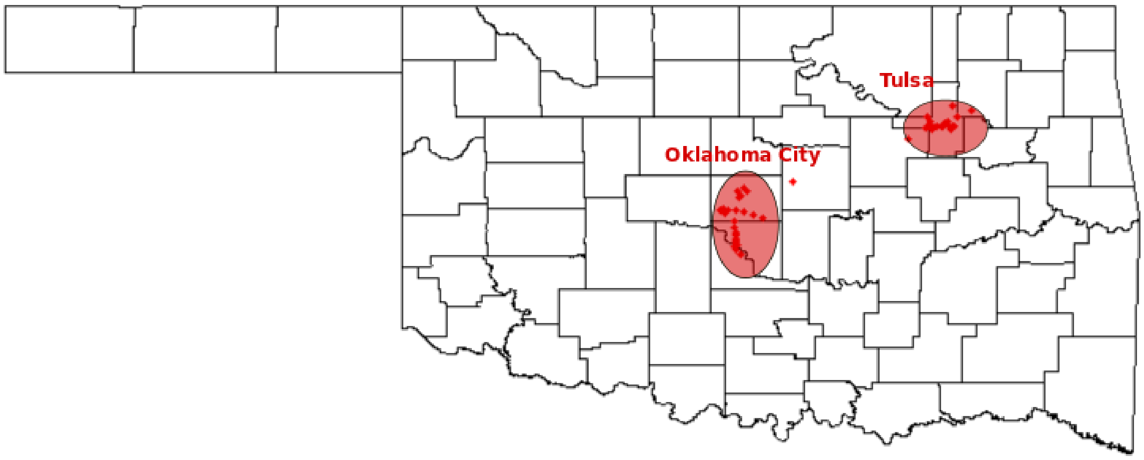

Figure 2: Location of Fixed Position Dynamic Message Signs

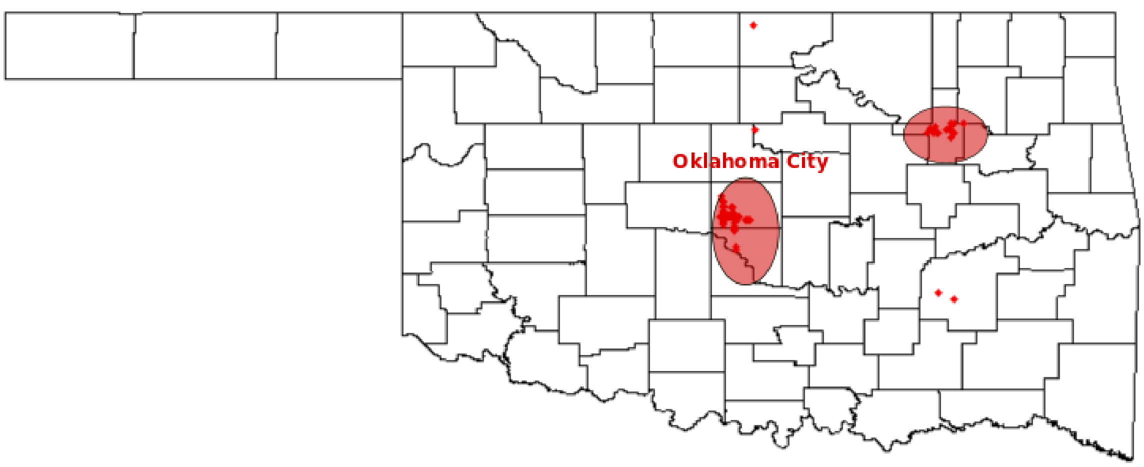

Figure 3: Location of Pole Mounted Cameras

Developing assets that are deployable to areas where infrastructure and measurement assets are not dense is a primary goal of this project. In this light, we acquired two camera trailers which are equipped with web-cameras mounted on a telescoping mast. Two Remote Traffic Microwave Sensor trailers were also acquired for detection of speed, volume, and occupancy traffic data and two Portable Message Signs were acquired to providing information to the traveling public. These devices are similar to those used to monitor traffic through roadway construction projects as part of Smart Work Zones [1].

A second closely related goal is to expand the types of data being collected for analysis. In light of this second goal weather sensing equipment was developed to augment fixed asset weather equipment. OU ITS and Oklahoma Climatological survey worked on the design and implementation of portable weather measurement systems. This included the determination of what variables would be measured and what equipment would be needed to assist in that measurement. These assets are deployable in a variety of situations and will assist in resource management such as snow plow and chemical media dispersion during snow and ice events. A second function for this equipment will be the integration of weather data into datasets for traffic and safety analyses.

A third goal was to harden ITS infrastructure assets against weather related or other natural disaster. With this aim in mind we have improved the facilities which house ODOT and ITS networks by acquiring and installing back-up generators and climate control systems. Data storage and servers assets have been located primarily in two locations for ODOT and ITS networks. The first location is a facility operated by OU ITS lab on University of Oklahoma's North Campus in the vicinity of Max Westheimer airport. The facilities house many of the server functions for both ITS and ODOT and required improvement to be genuinely suitable for housing this equipment. Firstly, the facility lacked proper climate control for the growing number of computing devices. In cases of extreme heat, power failure, or brown-out this vital link in the ODOT network and ITS network went offline. To address this issue back-up power generators and a solution was found for the climate control issues as will be discussed below.

Also hardened laptops have been purchased to assist in the maintenance and deployment of equipment. These laptops are currently being used by ITS lab managers to set up equipment throughout the state. A demonstration of this hardened equipment in use is in the case studies below. Lastly an expansion of server capacity was needed to maintain current levels of data analysis and control capabilities for the ITS lab.

1.1.1. Problem Statement

The University of Oklahoma (OU) Intelligent Transportation System Laboratory (ITS Lab) has partnered with ODOT, Department of Public Safety (DPS), Oklahoma Highway Patrol (OHP), and Oklahoma Highway Safety Office (OHSO) to develop a suite of systems that streamline the functions of traffic and law-enforcement management. To list a sample of the functions the ITS Lab has: ITS Lab supports the development and management of the ODOT private computer network, develops and deploys citation and ticketing software for OHP and DPS, and administers and develops the state's online system of collision reporting tools (known as SAFE-T) for OHSO.

The number of Dynamic Message Signs (DMS) on the ODOT network is expected to double in the next two years. Integration of Bluetooth or Wifi device detection systems for the estimation of vehicle travel times is expected within the next year. In the last year the Amber/Silver Alert system has been integrated into DMS control systems. There is a persistent trend for expanding the elements of ODOT's roadside network and integrating these elements into control systems that allow traffic stakeholders to manage these assets. This trend increases the computational and networking complexity of the ODOT ITS systems. This complexity has increased the hardware resources required to perform necessary tasks. The facilities previously housing the servers and equipment for this system had been satisfactory for a simpler network, but as the number of devices grew it became clear that the facility wasn't designed to support the thermodynamic load that what was becoming a server room generated.

As the importance of a data-centric traffic network grew so did the need to engineer significant reliability into the system. Again, it became apparent that the facilities had grown inadequate as computing systems went offline due to prolonged power outages due to ice storms and extreme heat and drought.

Data driven resource management and emergency management is another driver of the expansion of the ITS network. A previous OkTC project allowed OU ITS to develop automatic vehicle location (AVL) systems for snowplow and salt/chemical dispersion vehicles. For this project OU ITS developed systems to be installed in snow/ice mitigation trucks and visualize their deployment. This system also integrated weather data from Oklahoma Climatological Surveys meso/micro-nets and information from NOAA's NWS to allow traffic and emergency managers to visualize the coverage and efficacy of their de-icing and snow removal efforts. While this system has been developed and is currently being improved more research is needed into the effects of mitigation efforts and more data needs to be collected for analysis.

Interstate highway traffic flow data for the Oklahoma City Metro and for Tulsa is available through a public/private partnership with Traffic.com [2] as well as the development of ODOT owned assets. The data source for this traffic flow information is Remote Traffic Microwave Sensors (RTMS). The coverage for these assets is consistent throughout the OKC metro area and ODOT is developing assets in the Tulsa metropolitan area as well. City surface streets and rural areas provide excellent targets for traffic engineering and improvement as well as traffic flow data analysis. Expanding this capability will allow traffic engineers and researchers to expand their reach and improve the quality of data over simple pressure hose counting systems.

The ITS lab had a 2000 Chevrolet Express van with over 230,000 miles on it. This vehicle had become unreliable and was not capable of towing newly acquired equipment through often rugged roadside and construction site terrain.

Roadside and rural information is often vital during an extreme weather or natural disaster event. Mobile or portable DMS signs are vital to getting information to motorists during these events and to control traffic flow in the event of a natural disaster.

1.1.2. Background

Data systems have become increasingly important to transportation engineering and management in the last decade. Numerous data driven traffic management centers have been developed on both the state, regional and local level in the last two decades, for examples see [3], [4], [5] and [6]. Oklahoma has adopted a novel approach to traffic management systems and had developed a distributed network of traffic and emergency management personnel. That is, rather than geographically consolidating management personnel, network capabilities were developed to give access to centralized information systems. In this way assets maintained proximity to where they will be utilized and decision makers are closer to the field to help manage response.

ITS Lab has been a key player in the development of traffic and criminal software systems in the state of Oklahoma. The OU ITS Lab has been involved in the planning of the ODOT ITS assets since the beginning of ODOT's ITS network and has developed the hardware network and software assets needed for traffic management. Figure 1, Figure 2, and Figure 3 represents a snap-shot of some of the equipment deployed on Oklahoma's highway system. ITS Lab's lab manager is a primary maintainer and trouble shooter of ODOT ITS network devices. The lab manager logs tens of thousands of miles every year to fix equipment in remote locations throughout the state. The vehicle that he had been using to carry out this vital task had passed its intended life and become unreliable. ODOT's network has been consistently expanding over the last two decades which continually increases the maintenance requirements.

ITS Lab has been housed on University of Oklahoma's North Campus near Max Westheimer airport for more than 9 years. During that time, the computing assets of the ITS Lab, servers storage and battery back-up units have been housed in a closet that has been fitted for increased air-conditioning capacity. This facility has been plagued with power outages during the last several years, most notably the ice storm of 2007 ice storm which left 120,000 people without power for more than 1 week.

Figure 4: Emergency Services Responding to Downed Power Lines 2007

Power needed during the ice storm of 2007 far exceeded back-up battery capabilities and left OU ITS and ODOT without resources during a critical period. The primary advantage to this facility is that it is located close to the ODOT private network fiber optics cables that are on an easement in close proximity to the facility. ITS Lab devices not requiring access to the private ODOT fiber optic network were relocated to facilities that had diesel power on-site generation capabilities and sufficient climate control capacity, namely the National Weather Center. Images of some of the ITS server equipment, including servers and storage purchaced as part of this project and described in Sections 2.1.8 and 2.1.9 are shown in Figure 5. It is still a requirement to locate many of our devices at or near this facility because to access the private fiber optic network.

Figure 5: Server and Raid Storage Array Located at National Weather Center

This facility has also been problematic during times of high-heat. One of the primary concerns of running computing systems is to maintain sufficient climate control capacity to prevent thermodynamic breakdown of computing hardware. Improvements were made to the HVAC system in 2009 which were still insufficient and resulted in several computer-days of lost productivity, and the severity of the summers of 2011 and 2012 exasperated the situation. These events and the increasing importance of the systems housed there made it apparent that on-site electricity generation capacity was needed as well as improvements to HVAC systems.

Along with the need to harden systems and improve vehicles the need for ruggedized personal computing systems became a requirement. When ITS Lab employees were in the field there became an increased need to access network and hardware systems in the field. Computing at the side of the road is challenging as there is an increased likelihood of dropping computing devices onto hard surfaces or contacting the computer’s screen with sharp metal objects. Computer work in construction sites can eclipse the roadside risk. Investment in ruggedized and durable computing systems has been an increased need.

A data integration and dissemination project, "Roadway Weather Information System (RWIS) and Automated Vehicle Location (AVL) Coordination" (OTCREOS7.1-05, ODOT FY-09 SPR Item #2212) was conducted by the ITS Lab between October

2008 and July 2010 with joint funding by the Oklahoma Transportation Center and the Oklahoma Department of Transportation State Planning and Research division. The project's primary deliverables included methods, practices, and software to integrate various weather sensing devices and their data into Oklahoma's existing intelligent transportation network infrastructure, data storage systems, and dissemination platforms. The project's public service motivators were decreases in highway and bridge damage caused by unnecessary deicing actions and increases in motorist safety through improved reporting to transportation officials charged with mitigating inclement weather effects, policy makers, and the public. The efforts of this project work on the presumption that providing the various stakeholders with visibility of up to-the-minute deicing capabilities, roadway conditions, and effectiveness of relevant mitigative actions increase the efficiency of the State's transportation sector and the infrastructure supporting it.

Oklahoma Mesonet is another set of near-ground-level weather stations at roughly the county level. Data from these systems are received and processed by the Oklahoma Climatological Survey [7] [8] and are indicative of icing and snow events in the state of Oklahoma [9]. This prompted research by the ITS Lab to investigate weather-aware traffic information systems. The operations of these systems locally and the ability to relocate these systems gives an added capability to measure the influence of controlling variables, such as humidity, temperature and precipitation, and to study the effects of inclement weather on different roadway surface types. Another possible use for RWIS trailer systems is to study the effects on traffic flow of these weather events by collocating RWIS with RTMS.

Data storage, analysis, and dissemination continues to increase in importance in the state of Oklahoma. The ITS Lab produces a console system that allows a broad spectrum of traffic information users to access information about the road system and to control devices located on the ODOT network. Data from RMTS, RWIS, roadside cameras, Amber/Silver Alerts and other text to and from Dynamics Message signs, and the generation and dissemination of travel times are all relatively recent phenomena in

Oklahoma ITS. ODOT network communications and equipment devices have been outfitted with alarm modules to prevent vandalism and monitor equipment statuses. The OHP relies on ITS Lab servers for paperless citation and ticketing systems. These servers provide specialized storage and search software that assists law enforcement personnel by automating office functions and analyzing officer vehicle interaction history. All of these factors have increased server and storage demands and necessitated the purchase of new servers and RAID hardware.

1.1.3. Objectives

The high-level objectives of this project were to purchase and build systems required to modernize the University of Oklahoma Intelligent Transportations Systems facilities and equipment. This improvement project was to support increased demand of field engineering to maintain expanding networks, to improve facilities to support the increased importance of data-driven intelligent transportation systems, to improve systems for data storage and analysis, and to expand the availability of data sources to rural and non-highway environments.

Specific objectives for equipment were

- Improve usage modularity and develop abstract interface to roadway with RWIS
- Improve usage modularity and develop abstract interface to roadway with RTMS
- Improve usage modularity and develop abstract interface to roadway with DMS
- Replace vehicle which required excessive maintenance
- Improve ruggedness of vehicles
- Improve ruggedness of computing systems taken to the field
- Improve climate control of facilities for server-room
- Improve power reliability in emergency situations
- Expand storage and server capacity

To specifically address these goals the following actions were proposed:

1. Traffic/Weather Observation Trailers: trailers outfitted with pan/tilt/zoom cameras, temperature, humidity, rainfall, wind and infrared surface temperature sensors with solar panel primary and generator back-up power systems.
2. DMS Trailers: the use of this equipment for emergencies and the dispersal of travel time information to drivers provides an opportunity for study in the area of human factors relating to ITS.
3. Camera Trailers: these trailers provide assets when visual monitoring of traffic construction or other information is necessary for traffic research.
4. Speed Sensor Trailers: Expand the capacity to monitor traffic flow in non-metropolitan areas as well as on city surface streets.
5. Chevrolet Tahoe, Ford F250 Extended Cab: Replace outdated transportation options and allow for deployment of newly gained traffic information assets.
6. Purchase Diesel Generation Backup: Prevent server and storage failure of vital assets when they are needed most.
7. Purchase Dedicated HVAC System: Prevent damage to equipment during extreme weather events.
8. Acquire new server and data storage capabilities: Expand the capacity for data analysis and the ability to transmit the results of that analysis to the motoring public.
9. Acquire ruggedized laptops: Prevent equipment damage presented by the field environment.

Chapter 2

2.1. Development

The project team successfully developed and executed solutions to each of the primary goals. Assets for each of the goals were acquired and deployed to a high degree of completion. These assets are already providing benefits to ITS Lab, ODOT and the people of Oklahoma. Direct integration of M-ITS RTMS, RWIS and DMS assets into the ODOT console is in a high level of completion as well. Two vehicles were acquired to replace failing vehicles and to deploy new equipment. These vehicles have been tested deploying assets in extremely rugged environments and have proven to be extremely useful. Ruggedized computers were acquired and have been used for development of Highway Patrol software and used in field engineering tasks daily.

New servers and a raid storage device were acquired and located in the National Weather Center's server room that has built in diesel generation back-up and redundant climate control systems. It was decided that rather than invest equipment into the current facility on North Campus, ODOT would provide an air-conditioned communications hut and locate it on an easement adjacent to the current ITS Lab facility with access to ODOT fiber optic cables. A diesel generator was acquired to be attached to this com-hut. A high-level overview of the M-ITS Platform is shown in Figure 6.

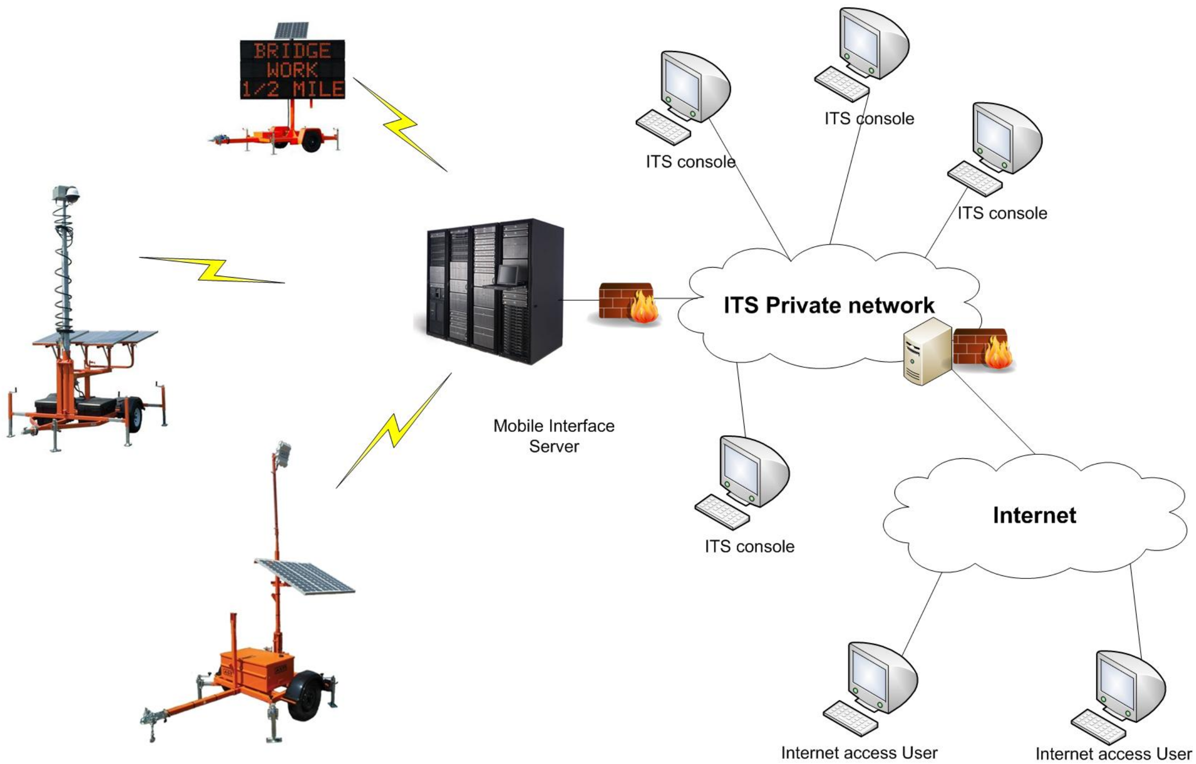

Figure 6: Device and Network Diagram Mobile ITS

2.1.1. Weather Observation Trailers

Weather in Oklahoma can be both dramatic and dangerous, and weather conditions hazardous to travelers can develop with little or no warning. Whether it's snow, sleet, hail, ice, rain, or fog, inclement weather reduces the safety of Oklahoma's highways, roads and bridges. In fact, within the last decade, only 47% of injury vehicle accidents occurred in clear weather. During this period, 4,034 fatal collisions occurred on Oklahoma's roadways in inclement conditions ranging from overcast skies to blowing snow. The Oklahoma Department of Public Safety records officer-reported weather conditions on all vehicle collisions requiring police presence. Statistics of reported weather conditions are reported to the Federal Highway Safety Administration. Oklahoma's rich history of excellence in meteorology and weather monitoring puts Oklahoma in a unique position to develop advanced weather-based traffic information systems.

Oklahoma is fortunate to have a rich set of in-state and remote sensing assets that monitor weather conditions including the Oklahoma Mesonet, the Oklahoma City Micronet [10], and Oklahoma Department of Transportation (ODOT) Road Weather Information System (RWIS) stations. The observations from these resources provide a high-resolution picture of weather conditions throughout the state.

Adding weather sensing capabilities to traffic observation trailers will allow the ITS lab to supplement the existing fixed weather sensor network in Oklahoma and to continue its research into weather related traffic and snow and ice mitigation techniques. The package of weather sensors to be deployed on camera trailers was designed by members of the Oklahoma Climatological Survey and were based largely on their existing Portable Automated Research Micrometeorological Stations [11]. To facilitate coincident weather and traffic observation, the following-trailer mounted equipment was purchased:

Temperature and RH Probe: measures temperature and relative humidity
Anemometer: measures wind speed and direction
Data Logger: To store and transmit information
NL115 Logger Interface: to store data on flash memory
WXT520: Second source of wind-measurement and relative humidity, primary source of precipitation information
IRT: Infrared reflection device to measure ice thickness on the roadway
Boom Pipe: To extend instruments from the main mast

The configuration of the mounted equipment is such that the measurement instruments are attached to a boom that extends from the main mast at a height of 6 ½ feet off of the ground. The boom is 2" square, which is of sufficient size to minimize vibrations and swaying in the wind, and extends 4' in both directions from the mast. The equipment mounted onto the boom as well as the equipment contained in a box on the trailer is shown in Figure 7.

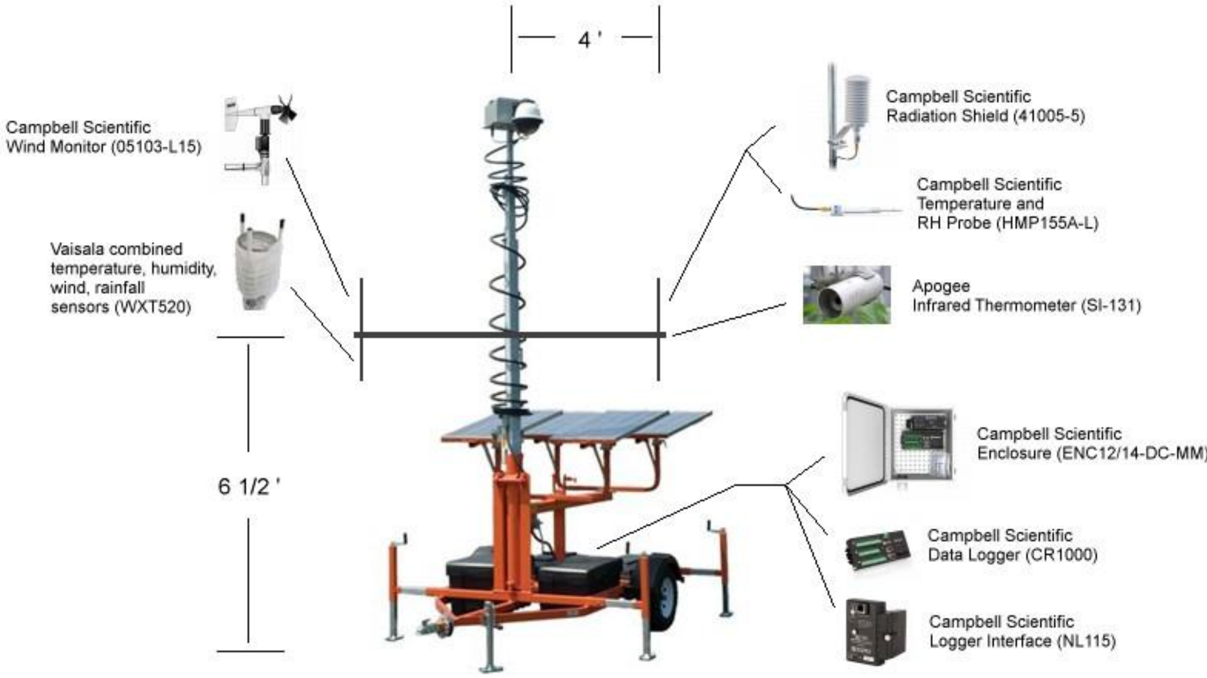

Figure 7: Weather Instrument Diagram Mobile ITS

Mesonet data has already proven itself as valuable in time-critical transportation construction project. In May 2002, one of the worst bridge collapse occurred near Webber falls, Oklahoma. Within 24 hours of the I-40 bridge collapse, Oklahoma Climatological Survey responded to a request from the Tulsa National Weather Service Forecast Office and the State of Oklahoma to deploy a temporary Oklahoma Mesonet station at the site. This station aided the Oklahoma Department of Transportation and Gilbert Construction in their effort to rebuild this crucial transportation corridor quickly and efficiently by providing relevant information about weather conditions, on site, needed in the pouring and curing of concrete. By providing an integrated picture of weather conditions and traffic observation, the platform developed as part of this project can provide similar assistance to future construction projects. In fact, as described in Section 2.2, shortly after the completion of this project, the camera trailers were deployed for observation of a first-of-its-kind-in-Oklahoma bridge construction project.

2.1.2. Dynamic Message Sign Trailers

Dynamic Message Signs (DMS) are a primary method of delivering information to the commuting public information relevant to the transportation systems that they are using [12]. Several factors have increased the importance of these devices in the last several years. The emergence and integration of the Amber and Silver Alert systems has added a since of time urgency to the dissemination of information. There is a federal mandate that requires that travel time information be posted on such signs during non-incident periods by 2014 [13], which has increased the importance of these signs as elements in traffic networks and management systems. Portable DMS have a role in situations where utility supplied power is unavailable or has been disrupted by unforeseen circumstances.

One of the two DMS trailers purchased as part of this project is shown in Figure 8. In addition to the case study described in Section 2.2, these signs have been used in tests of new communication technologies in collaboration with ODOT Technology Services Division. Figure 9 shows the OU ITS Lab Manager integrating a satellite communications to the serial interface of the sign on a test performed on September 6, 2012. It is anticipated that these signs will also be used in studies evaluating the effectiveness of vehicle speed feedback to drivers [14]. Other applications of portable DMS are disaster recovery, construction site notification and medium-term disruptions to traffic flow. DMS can also provide an additional measure of safety when researchers are in the field deploying or maintaining equipment. **This objective is 100% complete.**

Figure 8: Portable Dynamic Message Sign Displaying Test Message

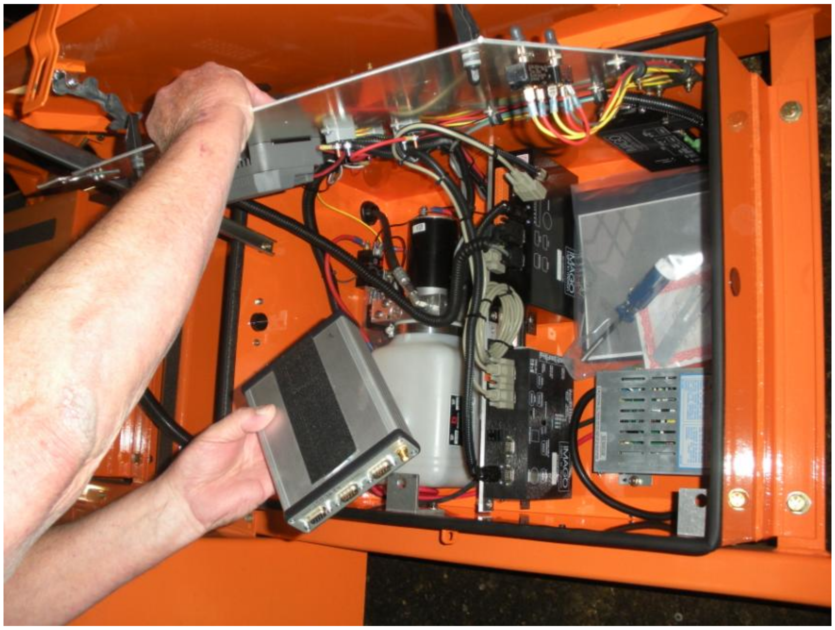

Figure 9: Integrating Satellite Communications During Test on Sept. 6, 2012

2.1.3. Remote Traffic Microwave Sensor Trailers

Remote Traffic Microwave Sensors (RTMS) have been increasingly deployed as a primary source of traffic flow data gathering. In general they gather Speed, Volume, and Occupancy data from traffic systems. To meet this need, we purchased 2 ASTI portable Queue Trailers. **This objective is 100% complete.**

Oklahoma has RTMS installed on its highway system predominantly in major metropolitan areas. The Oklahoma City metropolitan area has been instrumented by traffic.com, and the Tulsa area has been instrumented by ODOT. Data from these sensors has been aggregated [15] to compute predicted travel times to enable drivers to make informed routing decisions. Information from these devices is disseminated in several ways but the mechanism that reaches the greatest numbers of the traveling public is through the Advanced Traveler Information System [16] [17]. An example of this feedback is shown in Figure 10.

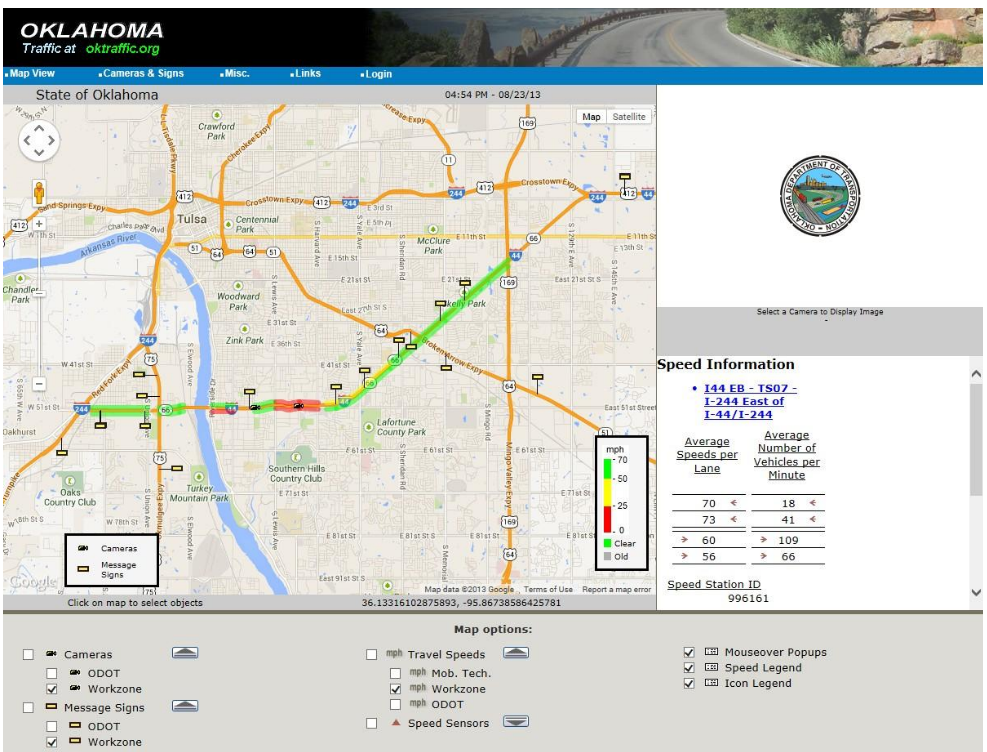

Figure 10: RTMS integration in ATIS

The ITS Lab purchased two portable RTMS devices with solar power and communications equipment to integrate the devices into the ODOT network.

Researchers at OU ITS Lab then developed listening services which are run on Linux virtual machines hosted by the servers purchased on this contract.

The basic design of the script is that the script initializes by listening for a statistical message broadcast from the RTMS device. Since each RTMS vendor uses slightly varying protocol the service has to be customized for different RTMS vendors. After the service receives its first statistical message it parses the settings data to verify that it corresponds to the data structure in the ATIS database where the data is to be stored. It notes the broadcast period which is also an element of the header packet of this message. Then it parses the data and stores it into the database. After storage the service sleeps until just before the next broadcast. If the settings of the RTMS are changed the script will update its sleep period. Perl is a scripting language that is designed to efficiently parse text, or as in our case data, streams. The service was written as a script in Perl.

A code sample is listed below:

```
while (1) {
            if($elapsedTime != (time - $lastMessageReadTime)){
            $elapsedTime = time - $lastMessageReadTime;
            PrintTime(time - $lastMessageReadTime);

            }
            if($elapsedTime > 300){exit;}
            $oldestByte  = $midByte;
            $midByte     = $newestByte;
            $newestByte  = ReadData( $sock, 1 );
            $lastTriplet = $oldestByte . $midByte . $newestByte;
            if ( $lastTriplet =~ m/\x{FF}\x{AA}\x{80}/ ) {    # We've got a header!
                if ($debug) {
                    print "\nWe've got a statistical message header....\n";
                }

                ###########  Read a header message         ###########
                $numberBytesHex = ReadData( $sock, 1 );
                $numberBytes = hex( sprintf( "%v2.2X", $numberBytesHex ) );
                $headerData = ReadData( $sock, $numberBytes );
                $checkSum   = ReadData( $sock, 2 );

                ###########  Parse a header message        ###########
                @headerDataBytes = split( //, $headerData );
                $msgPeriod = ord( $headerDataBytes[15] ) * 255 + ord( $headerDataBytes[16] );
                my $format = '%Y%m%d%H:%M:%S';
                $str1 = "20" . sprintf( "%v2.2X", $headerDataBytes[12] ) . sprintf( "%v2.2X",
$headerDataBytes[11] ) . sprintf( "%v2.2X", $headerDataBytes[10] ) . sprintf( "%v2.2X",
$headerDataBytes[8] ) . ":" . sprintf( "%v2.2X", $headerDataBytes[7] ) . ":" . sprintf(
"%v2.2X", $headerDataBytes[6] );
```

Field deployed hardware devices are notoriously prone to errors so a second script was developed to monitor the activity of the first script. That second script checks a database table to see which devices are to be monitored and what their IP addresses are. It then checks the Linux system process list to ensure that the service is running and to check the state of it as a process in terms of memory, CPU use, and process time. It also checks the database for the timestamp of a positive reading from the device. If the service isn't running or there has not been a positive reading for that device the service is restarted. In some of our pole mounted RTMS systems we have discovered a need to remotely power cycle the RTMS device due to the device being in a bad state. These devices tend to be widely distributed and manually power cycling the device can be time and cost prohibitive, so we have developed in house web-enabled relay devices that allow us to power cycle up to four collocated devices from a simple web interface. In this way we can power cycle the RTMS unit and the Raven modem. At the time of writing these relay devices have not been integrated into the trailer and some networking issues would have to be worked out, for example if the Raven modem is not responding it would be difficult to access the web interface. This is a possible avenue of future work.

To integrate this device into the ODOT network and mapping software an entry must be made in the ODOT speed sensors table as well as an entry in the rtmsmap table. This information will then be displayed on the mapping software as well as a segment of the roadway to indicate traffic flow. **This objective is 100% complete.**

2.1.4. Camera Trailers

Web based camera trailers provide a video data acquisition platform for monitoring changes in roadway configuration as well as other phenomena requiring visual data. To meet this goal ITS Lab purchased two ASTI Mobile Video Trailers with 440W solar panels and 12 6-point batteries. Networking these devices is performed using a Sierra Wireless Pinpoint X-modem which utilizes cellphone networks to transmit data. Integrating camera hardware is particularly difficult in the ODOT network framework as camera vendors each have individual APIs which vary sometimes between models. This was overcome by developing a custom image retrieval and delivery system that could interface with the separate camera models. The delivery system was designed so that images from the cameras could be viewed in a web browser as a streaming video.

After research of various alternative approaches to this problem, it was concluded that any streaming of webcam video over a website would involve the basic steps of obtaining a stream of images from the camera, saving those images on the web server, then letting the server redistribute them to web page visitors. Initially, camera streaming was implemented via high rate FTP of images to a web server. The image files on the server were individually overwritten with newer images, and the stream was displayed on a web page via Javascript timers that refresh an image frame.

FTP was not a preferable way of obtaining images from the cameras however, as a fair amount of overhead is involved with each FTP operation. The cameras were set to varying configurations of 2 to 5 frames per second at different resolutions, and in each of these cases, attempts to further increase the frame rate resulted in a large number of incomplete images within the video stream. This may have been because the cameras were reaching a limit in the number of FTP operations they could send, or the server may have been limited in how many FTP operations it could handle. Also, the server may very likely have had problems handling large numbers of FTP operations from large numbers of cameras.

A different way of retrieving frames from the cameras is to request frames from the camera in a streaming format over HTTP. The cameras support MJPG and MPEG2, which are the videos one sees if they directly connect to the web page hosted on the camera itself. This approach provides higher quality video, and more importantly avoids FTP overhead on the web server. It is possible to process an MJPG stream, which is composed entirely of individual jpg images, save those images, and redistribute them in the web page. A major obstacle was encountered in this approach, however. While cameras could send data requests to the web server (i.e. FTP), due to the server's security structure it could not send requests to the cameras in general (i.e. HTTP requests). Solutions considered involved opening paths in the server's firewall for all cameras, or some cameras support an HTTP upload feature in which an HTTP stream could be sent to the server from the camera, rather than being requested from the camera by the server. The main problem with opening paths in the firewall would be maintaining the list of cameras, and many older models of cameras do not support HTTP upload.

Regarding the streaming of the video on the webpage, various possibilities were considered. Most information on the subject encountered suggested that streaming video can be sent to web page users using one of a variety of streaming video formats, each of which requires a plug-in for the user's browser (Quicktime, Realmedia, VLC, an MJPG plug-in such as that provided by Axis, and Flash). The main drawback to any of these is that the user must be bothered with the plug-in, which would be undesirable for our users. If we were to choose one, the best choice would likely have been Flash. Flash is used by YouTube and Google video, and it has become a plug-in that is already installed on most users' computers. There exist conversion tools that can create Flash streaming video from MJPG within a Linux environment. Flash, however, has very little chance of ever being supported on the iPhone, which is used by many of our users.

An alternative idea makes use of a Javascript-based technique to push frames to the user. It doesn't require any sort of plug-in, but it still had issues that needed to be worked out. For one, as new frames are being pushed to the user, on some systems the user's mouse will flash back and forth between busy and normal, and the status bar will constantly update, stating that it is downloading new images. The other problem is that this technique lends itself to memory leak issues in several browsers. Observing the memory usage, no problems were noticed on some machines, but on others, memory usage continuously grew in both Firefox and Internet Explorer 8, with Firefox capping out at about 85MB, and Internet Explorer growing indefinitely.

A design concern was also the potential recording of the video streams, but the Javascript-based delivery technique handles this concern well. The web page could be developed so that individual camera images could not be accessed unless the user is actually viewing the site, which applies to the Javascript-based image streams as well. No outside applications would be able to programmatically retrieve the images and save them elsewhere. A Flash-based technique would also have built in protection against saving streamed video. It would still be possible for someone with dedication to create a program to take screenshots of their computer, crop out the video images, and save them, but there's little protection against that short of not streaming the video.

After some consideration HTTP-based streaming methods were developed for the cameras. Newer camera models capable of HTTP upload were configured to connect to a CGI script on the web server to upload images. For older camera models, holes were opened in the firewall to allow the web server to connect to them and obtain an MJPG stream. All previously running FTP services that were running on the cameras were disabled. With both HTTP-based methods completed, it was found that the HTTP upload option did not offer much greater performance than upload via FTP, as the cameras were still uploading individual images. Maximum sustainable frame rates were about 4 or 5 frames per second.

Therefore it was decided that the best way of obtaining quality streams from the cameras would be to open any necessary holes in the firewall and request HTTP streams from the cameras. All HTTP uploads were turned off, and Perl scripts were developed to access the MJPG streams from the cameras over HTTP, parse the streams, and save the images on the server for redistribution. The primary code of these scripts is shown below.

```
$i = 0;
$start_time = time();

my $url =
"http://".$user_pass.$ip.":6969/axis-cgi/mjpg/video.cgi?resolution=".$res;
if($port_6969 == 0){
  $url =
"http://".$user_pass.$ip."/axis-cgi/mjpg/video.cgi?resolution=".$res;
}

my $output_jpg = $ip_file_base.$ip_file.".jpg";

my $jpeg_length;
my $jpeg_data;

#each line of CURL dilineated by:
$/="--myboundary\r\n";

open CURL, "wget -T 5 -nv -O - '$url' |";

while ( <CURL> ) {

  if($cutoff_seconds > 0){
    if($i == 100){
      $i = 0;

      #quit if past cutoff time
      if( (time() - $start_time) > $cutoff_seconds){
        last;
      }    }else{
      $i++;
    }
  }

  #if contains Content-Type -- not empty first line
  if( $_ =~ m/Content-Type:/ ){

    #if contains Content-Length: -- 221 feed
    if( $_ =~ m/Content-Length:/ ){

      $_ =~ /Content-Type: image\/jpeg\r\nContent-Length:(\d+)\r\n\r\n(.*)/s;

      ($jpeg_length, $jpeg_data) = ($1, $2);
      $jpeg_data =~ s/\r\n--myboundary\r\n$//;

      next if $jpeg_length != length($jpeg_data);

    }else{ # -- 2120 or 2140 feed

      $_ =~ /Content-Type: image\/jpeg\r\n\r\n(.*)/s;

      $jpeg_data = $1;
      $jpeg_data =~ s/\r\n\r\n--myboundary\r\n$//;
    }

    my ($comment_length, $comment_data) = ($jpeg_data =~ /\xFF\xFE(..)\x0A\x03(.{260})/s);
    $comment_length = hex unpack("H4", $comment_length);
    $comment_data =~ s/[^[:print:]]//gs;

    open (MYFILE, '>'.$output_jpg);
    print MYFILE $jpeg_data;
    close (MYFILE);
  }
}
close (CURL);
```

The scripts were set to request the MJPG streams from the cameras at a resolution of 480x360. Other available resolutions to request were 1920x1080, 1280x720, 640x480, 480x360, 320x240, 240x180, and 160x120.

The Javascript-based video streaming technique for the webpage took some time to develop, but once implemented proved reliable. Initially the standard *xmlhttprequest* request method from the AJAX library was considered to obtain images, but research into the method revealed that it is designed for obtaining text-based data and does not work well for binaries such as the MJPG stream from the cameras. Instead, the standard Javascript *onload* even from the *Image* object was used to stabilize the video and implement dynamic frame rate adjustment, although this involved the resolution of a persistent syntax issue. The *Image* object is a good way to dynamically preload and download images, and the *onload* event fires when the image has been downloaded. However, the original usage of the event obtained from documentation did not function reliably. That original syntax, which set the event to run a function when it fires, was:

```
oImgObject = new Image();

oImgObject.onLoad = image_loaded();

oImgObject.src = "img_url";
```

After extensive testing, it was discovered that this syntax simply calls the *image_loaded* function right away, before the *Image* object src has even been set, and ignores the *onload* event. It was troublesome to detect, as the function is still run, just at wrong time. Changing the syntax to:

```
oImgObject.onload = image_loaded;
```

causes the *onload* event to fire and run the *image_loaded* function only when the image has finished downloaded, as it should. A different syntax possibility of '*onLoad = image_loaded*' ignores the *onload* event, while '*onload = image_loaded()*' causes a Javascript error.

The core components of the completed Javascript-based web page streaming video solution are shown below:

```
function do_play(){
  if(hist_fnames.length > 0){
    playhist = 1;
    cam_i++;
    if(cam_i == num_loop_images){
      cam_i = 0;
    }
    prev_image_loaded = 1;
    cam_img_refresh();

  }else{
    playhist = 0;
    document.getElementById("hist_image").src =
      'cameras/show_img.php?valid=1&fname=none&trailer_cam=1';
    document.getElementById("hist_time").innerHTML = 'No Images Found for Requested Dates';
  }
}
```

```
function cam_img_refresh(){
      if(prev_image_loaded == 1){
        miss_count = 0;

        if(loopImages[cam_i] == 0){ //not yet loaded
          prev_image_loaded = 0;
          new_image_url = 'cameras/show_img.php?valid=1&fname=' + hist_fnames[cam_i] +
                          '&trailer_cam=1';

          pre_time = (new Date()).getTime();

          loopImages[cam_i] = new Image();

          // set what happens once the image has loaded
          loopImages[cam_i].onload = update_img;

          // preload the image file
          loopImages[cam_i].src = new_image_url;

        }else{  //already loaded in previous loop

          if(loopImages[cam_i] != -1){
            document.getElementById("hist_image").src = loopImages[cam_i].src;
            document.getElementById("hist_time").innerHTML = hist_times[cam_i];
          }

          if(playhist == 1){
            cam_i++;
            cam_refresh_time = base_cam_refresh_time;

            if(cam_i == (num_loop_images - 1) ){
              cam_refresh_time = pause_mult*base_cam_refresh_time;
            }else if(cam_i == num_loop_images){
              cam_i = 0;
            }
          }
        }
        miss_count++;

        if(miss_count >= max_miss){

          //image failed to load, set to skip
          loopImages[cam_i] = -1;

          cam_i++;
          cam_refresh_time = base_cam_refresh_time;

          if(cam_i == (num_loop_images - 1) ){
            cam_refresh_time = pause_mult*base_cam_refresh_time;
          }else if(cam_i == num_loop_images){
            cam_i = 0;
          }

          prev_image_loaded = 1;
          miss_count = 0;
        }
      }

    //try / load again
    if(playhist == 1){
      cam_timer = self.setTimeout("cam_img_refresh()", cam_refresh_time);
    }
}
```

```
function update_img() {
  if( (loopImages[cam_i] != 0) && (loopImages[cam_i] != -1) ){

    document.getElementById("hist_image").src = loopImages[cam_i].src;
    document.getElementById("hist_time").innerHTML = hist_times[cam_i];

    if(playhist == 1){
      //set to next for next cam_img_refresh
      cam_i++;
      cam_refresh_time = base_cam_refresh_time;

      if(cam_i == (num_loop_images - 1) ){
        cam_refresh_time = pause_mult*base_cam_refresh_time;
      }else if(cam_i == num_loop_images){
        cam_i = 0;
      }
    }

    prev_image_loaded = 1;

    post_time = (new Date()).getTime();

    var frames_per_s = 1000 / (post_time - last_time);
    if(frames_per_s > 1){
      frames_per_s = Math.round(frames_per_s);
    }else{
      frames_per_s = Math.round(frames_per_s*100)/100;
    }

    var fetch_time = post_time - pre_time;

//    document.getElementById("feedback").innerHTML = "Actual Frames / s:  " + frames_per_s;
//    document.getElementById("feedback").innerHTML += "<br>Fetch Time:  " + fetch_time;

    last_time = post_time;

    //if already greater than a tick, call right away without
    // waiting for next tick
    if(fetch_time > cam_refresh_time){
      if(cam_timer > 0){
        clearTimeout(cam_timer);
        cam_timer = 0;
      }
      if(playhist == 1){
        cam_img_refresh();
      }
    }
  }
}
```

The Javascript-based streaming solution is capable of displaying statistics overlaid on top of the video that can be used to monitor the solution’s performance. These statistics include the Actual Frames - the frame rate achieved between the user and the web server, the Fetch Time - the time in milliseconds it's taking to download frames, and the Target Frames - the frame rate the streaming solution is trying to achieve. The algorithm is one where the next frame is not loaded until the previous one has been completed, resulting in a variable actual frame rate. If frames are not coming in fast enough to meet the target frame rate, the target frame rate is slowed to achieve smoother video playback. This variable frame rate greatly assists the playback of video on potentially low bandwidth devices such as the iPhone.

To enable video streaming from the cameras to be carried out efficiently, an on-demand architecture was also developed on the web server in which the server only streams video from a camera if a website user has requested the feed. Using this architecture, there is one stream per camera regardless of number of visitors, and streams are stopped after a few minutes of inactivity. For some unreachable cameras, it turned out that many instances of the Perl script used to obtain images from the cameras were running forever. A timeout was added to that script to only attempt to contact the camera for 5 seconds before terminating.

The on-demand streaming video framework developed thus far worked well to display current video streams in a website, but we found that it would also be desirable to continuously capture and save high-definition images from the trailer cameras at fixed time intervals. These still images could then be utilized to display time-lapse video. To that end, the framework was modified to be able to request still images from the cameras in addition to the MJPG video streams. The Perl script that was developed to obtain still images is shown below.

```
my $img;
open CURL, "wget -T 5 -t 10 -v -O -
'http://root:pass@".$ip.":6969/axis-cgi/jpg/image.cgi?resolution=".$res."&c
ompression=30' |";
binmode CURL;
while ( <CURL> ) {
  $img .= $_;
}

if( length($img) > 0){
  open FILE, ">", $ip_file_base.$ip_fname;
  print FILE $img;
  close FILE;

  $querystr = "INSERT into trailercam_imgs values('".$ip."',
    '".$mysql_time."', '".$ip_fname."', 'N')";
  $ref = $dbh->do($querystr);
}
close CURL;
```

Initially, we were working with a 50MB per month data limit on the cellular plan used to communicate with the trailers. The Perl script above was set to obtain an image from each trailer camera every 15 minutes, 6am to 7pm on Monday through Saturday at a resolution of 352x240 and 30% compression, and save it with a timestamp appended to the image filename. At about 20 KB per image, that calculated to around 50 MB per month. The filename, camera IP address, and timestamp are also saved in the web server database for use in the Javascript-based video streaming. Generally it takes several connection attempts to successfully get an image, and the script also includes modifications to handle that well.

A private, dedicated web page for viewing still images from the trailer cameras was developed. The latest images stored in the database for each camera are displayed at the top of the page, below which a Google map with a pin at the trailers' latitude and longitude is shown, and a playback section is displayed at the bottom. The images at the top of the page are labeled *PTZ Cameras*, with a 'Control Camera' displayed beneath each image that directly links to the camera's web control interface. The page also displays the username and password needed to control the cameras.

The playback section at the bottom is labeled *Time Lapse Cameras*. The user can select which trailer and what dates they desire to view, then when they hit play, a list of images is obtained from the database and played. The video playback can be controlled via several playback control buttons overlaid on top of the video. These controls allow the user to pause or play the video, speed up or slow down the video when it is playing, and step through image frames when the video is paused. When the user selects a trailer, the page immediately shows the last image from the selected trailer. This behavior had to also be integrated into the playback controls. When the user selects a trailer, video playback is paused, but the user could still see unexpected behavior if they changed trailers then attempted to cycle through frames before loading the images for that trailer with the play button. The page could have been modified to load all images upon trailer selection, but it would be too easy for a user to overload the page while switching trailers. Instead the playback controls were modified so that all controls except the play button are hidden until images are loaded. The image loading and checking code from the Javabased-camera streaming solution also had to be incorporated into the playback controls. Once completed, the playback section successfully presented a controllable, stable time-lapse video that waits for each frame to be loaded before displaying further video.

To assist in the positioning of the cameras upon deployment, a small, stand-alone page capable of live-streaming the trailer cameras was also developed. This page could be viewed on mobile devices in the field and greatly assisted in placing the trailers and cameras so that the desired view could be recorded.

After the above page was completed, the cellular plan used to communicate with the trailers was upgraded to have a bandwidth of 5 GB per month so as to allow us to obtain and store high definition images for the time-lapse video. It was also desired to obtain images every 10 minutes instead of every 15 minutes. At this point, we tested the image file size and bandwidth associated with several combinations of image resolution and compression. These combinations are shown below.

```
Image filesizes for varying resolutions and compressions:

352x240, 30%: ~20K
352x240, 70%: 10K
352x240, 0%: 75K

320x180, 0%: 55K
320x180, 30%: 15K
320x180, 70%: 7.5K

800x450, 0%: 260K
800x450, 30%, 55K
800x450, 70%, 30K

1280x720, 0%, 600K
1280x720, 30%, 120K
1280x720, 70%, 65K

1920x1080, 0%, 1.3M
1920x1080, 5% 690K
1920x1080, 10% 470K
1920x1080, 15% 370K
1920x1080, 30% 265K
1920x1080, 50% 175K
1920x1080, 70%, 125K
1920x1080, 100% 35K

Monthly bandwidth at 1920x1080 resolution:

50% compression : 575 MB / month
30% : 875 MB
15% : 1.2 GB
10% : 1.6 GB
5% : 2.3 GB
0% : 4.3 GB
```

The calculations for the monthly bandwidth requirements were arrived at using the following formula:

```
bandwidth = ( ( number of hours * 6 images/hour ) + 1 image ) * 31 days * image filesize
```

After this analysis, the Perl script used to obtain still images from the cameras was modified to get images every 10 minutes, 7am to 8pm every day at resolutions of both 1920x1080 and 352x240 at 30% compression.

The camera trailers page developed thus far had not been designed with high definition images in mind. The existing page was useful to quickly look at imagery, so new pages were designed to show the HD images, and 'high definition' links were added to the original page. The new high definition pages can be used to view or play back the high definition images, and also have a full screen option. The full screen option was designed to display the camera imagery at a size that fits the browser window yet maintains a proper aspect ratio. With the full screen option on, the F11 button can be pressed to place the browser into full screen.

As a backup to the collection of camera imagery over the cellular network, the cameras on each trailer were also configured to save high definition snapshots to a local SD card every 5 minutes.

After the successful purchase and integration of the trailer cameras, the trailers were deployed. They are currently being used as described in the case study below. **This objective is 100% complete.**

2.1.5. Vehicle Acquisition

One Ford F250 Super Duty 4-wheel drive vehicle was purchased and one Ford Expedition 4-wheel drive vehicle was purchased. These vehicles were purchased and have been outfitted with tool storage equipment and trailer hitches to aid in transporting trailer devices to their deployment locations. These vehicles have become daily use assets of the lab and were integral in camera deployment and DMS deployment in the two case studies mentioned below. **This objective is 100% complete.**

2.1.6. Improved HVAC For Server Rooms

Rather than purchase air conditioning units to install in a facility that we lease from a third party, as a result of this project, ODOT agreed to purchase and locate a communications hut on an easement directly behind the current leased facility. The communications hut is specifically designed to house the server and networking equipment that is housed in the closet of the leased facility and allows us more control of the physical space that our systems are housed in. **This objective is 80% complete.**

2.1.7. Backup Power Generation For Server Assets

To meet this objective we purchased one automatic standby generator, and one generator transfer switch. We also bought a 250 gallon propane tank with a regulator. Backup power generation for the aforementioned communications hut will allow uninterrupted use of the vital networking and data processing equipment for the Department of Transportation. In fact this back up power generation capacity has already been tested when Oklahoma Gas and Electric switched the power over to smart-grid monitored technology and the facility was without utility provided power for several hours. During this period all networking and server functions were maintained and it provided an excellent test of this added capability. **This objective is 100% complete.**

2.1.8. Server Acquisition

To meet this primary goal 4 Dell PowerEdge R610 [18] servers were purchased and are temporarily housed at the National Weather Center's server room. This avoided adding thermodynamic load on our facilities. These servers are used as "sandboxes" for development and testing of new ITS applications before they are placed on the deployment Oklahoma ITS network. They also used in the implementation of communication mechanisms with the Mobile ITS Platform and in Mobile ITS data collection. These servers are further being leverage for processing traffic incident location data. This data is currently reported using either paper forms or their electronic equivalent [19] through a system called the Mobile Data Collection Systems (MDCS) that is deployed statewide to the Oklahoma Highway Patrol (OHP) and partner agencies including the Oklahoma County Sheriff's Office, the City of Edmond, and the City of Woodward, as well as the eventual replacement for the existing MDCS called Police Automated Records Information System (PARIS). PARIS is being developed currently at ITS Lab and is customized to the needs of law enforcement users in Oklahoma. This software automates the traffic record chain from the police officer who collects the data to Oklahoma Department of Public Safety or the court system improving the time from the interaction of the officer on the roadside to receipt of the traffic record. An OHP Trooper using the MDCS inside his vehicle is shown in Figure 11.

Figure 11: OHP Trooper Utilizing Mobile Data Collection Systems In a Patrol Car

Servers acquired through this project are additionally being utilized for research into traffic flow and traffic safety. Specifically these machines were used for the Fatality Accident Reporting System research funded by OkTC through project OTCREOS11.1-06. This analysis integrated several previously disparate data sets of traffic collisions and two sets of roadway characteristics data obtained from ODOT the Federal Motor Carrier Safety Administration. ITS Lab partnered with researchers in the Oklahoma State University Geography Department to study the relationship between roadway characteristics and fatality collisions. The ITS Lab was also able to correlate this data to the effects on traffic flow on collisions. This information promises to be academically interesting for research into traffic clearance and the effects of collisions on traffic flow. This research was made possible by the availability of this hardware. Images showing the ITS computing infrastructure and the equipment purchase as part of this project in particular were shown back in Figure 5. **This objective is 100% complete.**

2.1.9 Raid Storage Acquisition

To meet this primary goal a Dell PowerVault MD3200i series 24 TB iSCSI Storage Array was purchased. This device allows us to keep up with the storage demands that much of our increased computing capacity has generated. Storage capacity has greatly increased as police software has expanded throughout the state with OU ITS Lab results including the Mobile Data Collection Systems described in Section 2.1.8.. These standalone applications and web-applications collect and transmit citation, crash reports and other traffic records to expedite reporting. ITS Lab has been developing many new database related products and this device has enabled us to keep up with growing storage demands. Also 4 Dell PowerConnect 5448 GbE Managed Switches were purchased to handle the increased network switching demands of these two primary objectives. **This objective is 100% complete.**

2.1.10 Ruggedized Computing Device Acquisition

Two Panasonic Toughbook CF-30 were purchased for development and field engineering purposes [20]. Oklahoma Highway Patrol (OHP) deploys these model of devices in Troopers' vehicles to interface with electronic citation and ticketing devices which makes them an ideal addition to ITS Lab to test new software and peripheral interfaces. Since these devices match those used by OHP, one of these laptops has been used extensively in testing and development of the existing and soon-to-be-deployed Mobile Data Collection Systems. These devices also are extremely resistant to damage and are used daily by OU ITS Lab members to interface with roadside equipment for installation and maintenance. **This objective is 100% complete.**

2.2 Case Studies and Assessment of Usefulness

The following are two case studies of events that occurred during or immediately after the duration of this project that highlight the usefulness of this equipment investment in the research and operation of the OU Intelligent Transportation Systems Laboratory and in its mission to provide hardware and software support to transportation stakeholders in the State of Oklahoma. Much of the equipment acquired during this project is used in the day to day operation of the OU ITS Lab. These two cases demonstrate exemplary uses.

2.2.1 Moore Tornado Disaster Assistance

On the afternoon of May 20, 2013 an EF5 tornado struck Moore, Oklahoma causing damage that is estimated to be in the billions of dollars. The storm had a catastrophic impact on the infrastructure of Moore. All of the fixed position DMS in the local vicinity lost power and communications networks failed as well. Over the next several days, Ekasit Vorakitolan, OU ITS Lab manager was repaired damaged fixed position DMS, attempted to re-establish communications with signs and other fixed position hardware, and repaired damage to fiber-optic cables. The day after the storm, Gayland Kitch, Director of Emergency Management, City of Moore requested use of portable DMSs to provide information to the citizens of Moore and to manage traffic in the city. The signs and the trucks to deploy and re-deploy these dynamic message signs to the City of Moore were provided by this project. Deployment of Mobile ITS equipment was performed by OU ITS Lab personnel.

Over the next few months, the OU ITS Lab continued to support the city of Moore by updating the message signs and repairing damage to traffic infrastructure in the area. Mobile ITS Platform assets were a catalyst for the formation of new working partnerships with municipal transportation agents. Use of portable, dynamic message signs in emergency response to improve public safety through dissemination information to motorists has been shown to be a valuable tool for providing timely information and guidance after a natural or human-caused disaster [21]. Emergency deployment is a primary application of the Mobile ITS Platform and demonstrates the beneficial impact that the Mobile ITS project has already had and will continue to have for the citizens of the state of Oklahoma.

Figure 12 shows one of the deployments of the Mobile ITS portable signs on SW 19th Street in Moore, OK near the intersection with Telephone Road. Figure 13 show a screen shot of the graphical interface used to remotely set the dynamic message for that sign through the Oklahoma Intelligent Transportation System. Finally, the log in Figure 14 shows communication with this sign following the National Transportation Communications for Intelligent Transportation System Protocol (NTCIP).

Figure 12: Ekasit Vorakitolan setting up portable DMS in Moore, OK

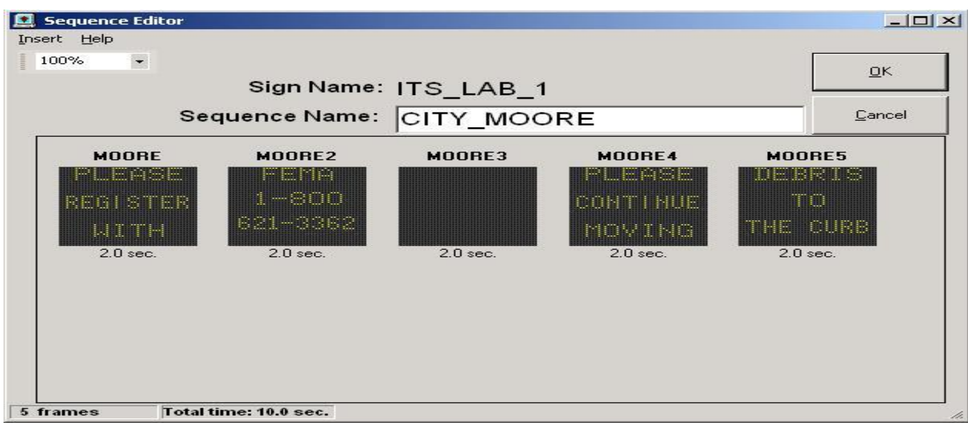

Figure 13: Screenshot of messages used during disaster recovery.

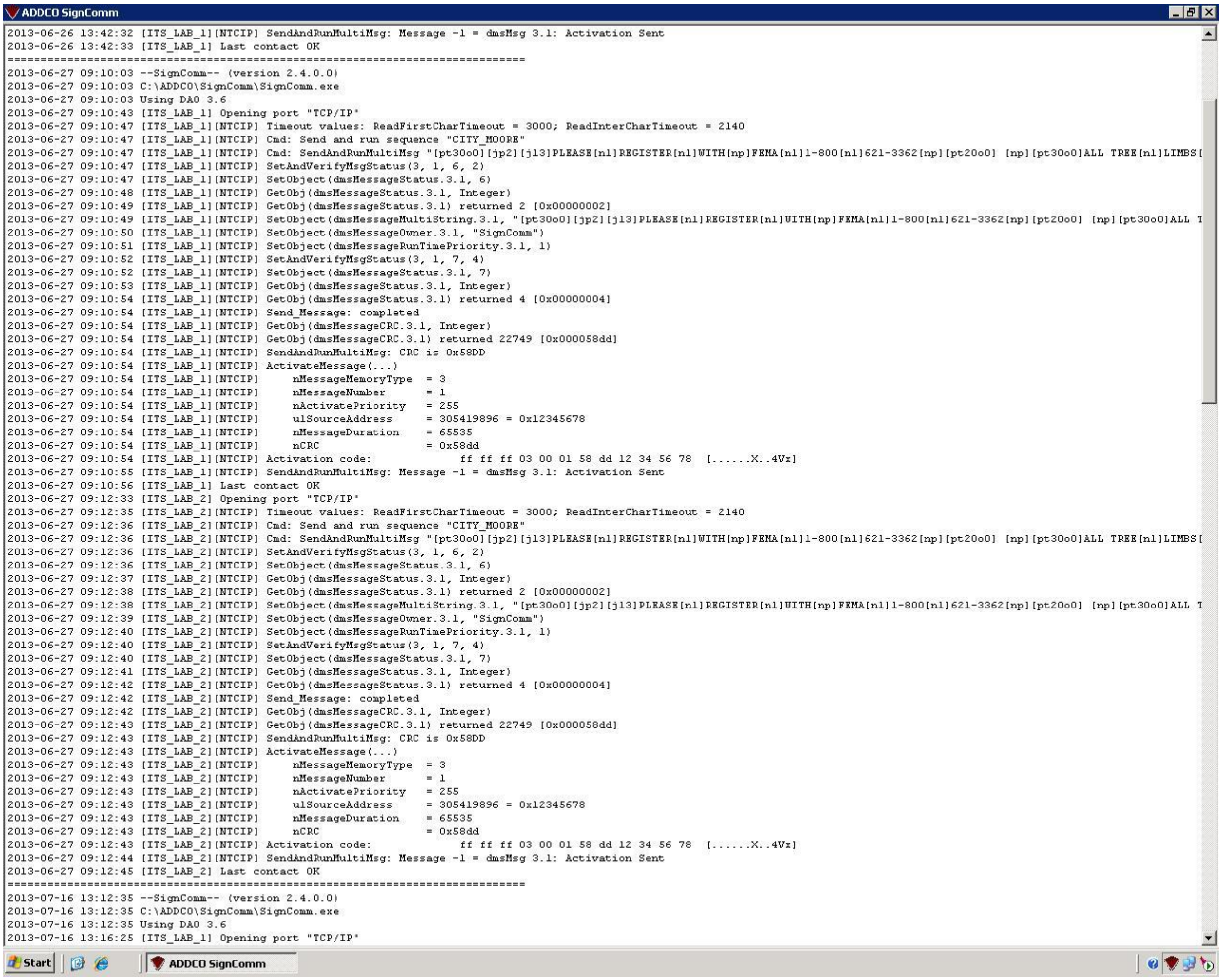

Figure 14: Log of NTCIP messages sent to Moore sign

2.2.1 Creek County Bridge Construction Project

In December 2012, ODOT proposed the construction of a replacement bridge using new construction techniques designed to speed the replacement of a bridge on Highway 51 near Mannford, Oklahoma. Manhattan Construction proposed to build the support for the new bridge underneath the old bridge. When construction of the replacement is complete, the old bridge will be demolished and the new bridge moved into place. This first-of-its-kind-in-the-state construction project will greatly reduce the time during which travel is disrupted and was highlighted as evidence of Oklahoma's innovation in highway construction by the U.S. Secretary of Transportation [22]. It has also received significant attention from local media [23] [24].

ODOT requested that the ITS Lab find methods to document these novel construction techniques. ITS Lab used the two camera trailers provided by this project and described in Section 2.1.4. In collaboration with ODOT, these trailers were located so that they had two unique vantage points on the project. Members of the ITS Lab transported the camera trailers to the construction site and set up the cameras. There was a major development effort to get the images, taken every 10 minutes, to the storage servers in Norman. A web interface was developed so that the performance of the cameras could be monitored. These images provide both a live view of construction as well as a time-lapsed view.

Due to the unusually high amounts of precipitation received in the Spring and Summer the river spanned by the bridge under construction flooded, putting the cameras in peril. The Ford F-250 truck, described in Section 2.1.5 was vital to relocating these devices in the muddy and treacherous terrain. This project has given ODOT the capability of doing after-action analysis to evaluate this technique and possibly improve the approach and speed this new construction process even further. The time-lapse video will also be used to as a public information tool.

Figure 15: Mobile ITS Camera Trailer

Figure 16: Vantage point of camera trailers.

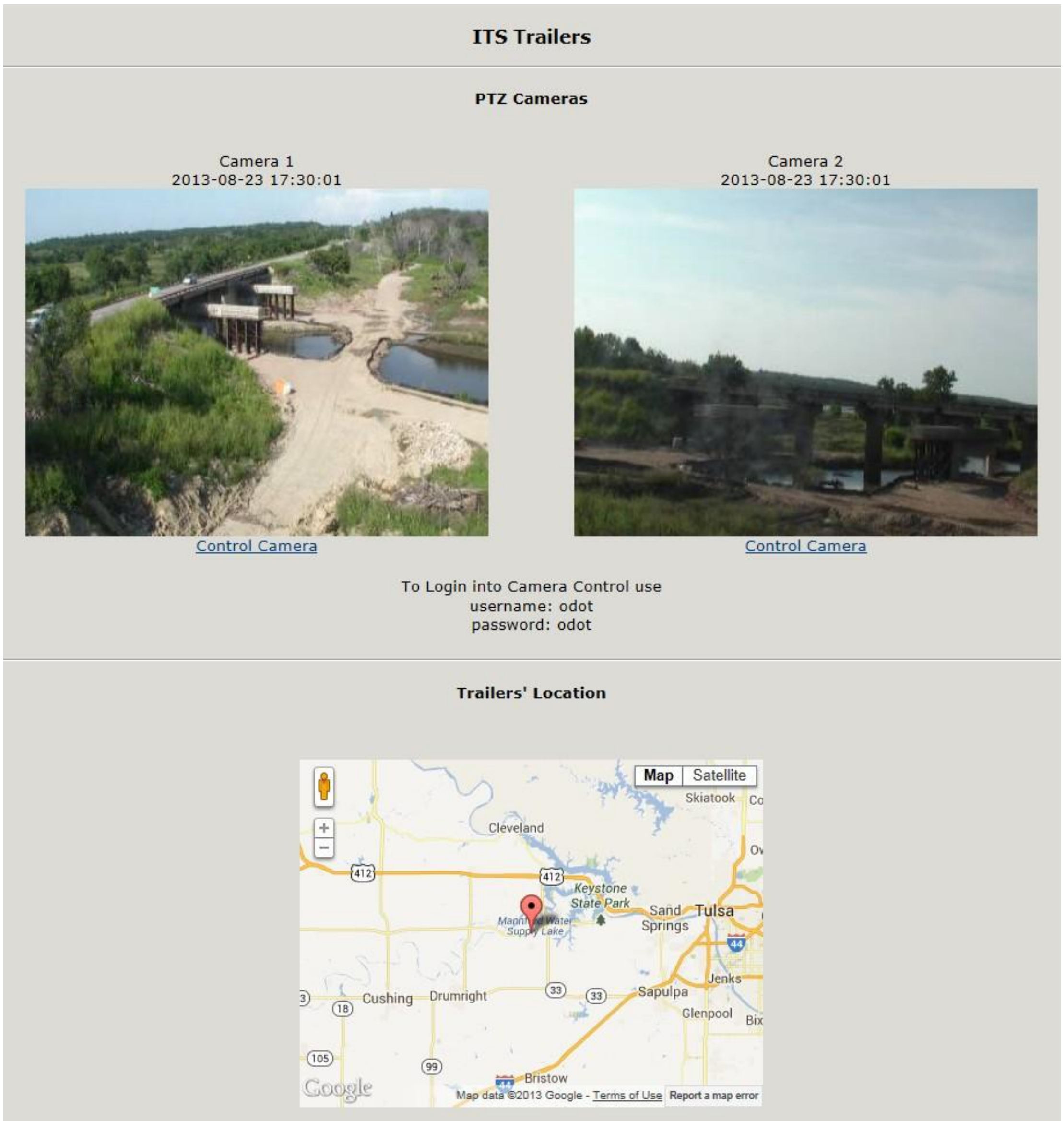

Figure 17: Locations and Camera Interface

Chapter 3

3.1. Technology Transfer

The Mobile ITS development efforts described in Section 2.1 resulted directly in the production of new, deployment-ready technology that is specifically designed to achieve the high-level project objectives given in Section 1.1.3. The equipment purchased for this project has been deployed and tested and are currently making a significant impact for the end users.

In the near future, the continued research into traffic flow and travel time will result in accurate travel time estimation. These estimates will be displayed on fixed position DMS located along the highway. Knowledge gained from these devices is already making a significant impact. This impact will increase over the next several years. Continued integration of weather data and research into the effects of weather variables on the commuting public will aid ODOT in more efficient deployment of snow plows and chemical de-icing. The addition of computing resources and networking devices has already had a significant impact on the search speeds and data transfer to electronic ticketing devices. The assets acquired during this project have greatly improved the development and integration processes.

Impacts on data systems collection, analysis and dissemination is maturing in the traffic engineering and management arena making investments in this field have an immediate and lasting impact on the motoring public. As more devices are added to the Department of Transportation network, increased amount of maintenance, data processing and networking will be required to run this network. The investments of this project directly impact that.

Chapter 4

4.1. Conclusions

This project evolved the creation of a unique Mobile Intelligent Transportation System (ITS) Platform. This equipment grant provided novel ITS components for rapid deployment, including custom weather sensor instrumentation. Many of these components are portable versions of ITS components that exist in fixed locations on the Oklahoma ITS network, including cameras, traffic sensors, and message signs. Through wireless communication, data from each of these are integrated and analyzed in OU ITS Lab servers and are made available to the Oklahoma ITS network. This new resource enables the OU ITS Lab to perform world-class traffic studies and provides a test bed for evaluating new ITS components and techniques. The equipment provided through this grant will provide new sources of data for studying traffic, including travel time prediction, traffic/weather correlations, construction parameters, and sensor/actuator effectiveness for roads, bridges, and travelers, both private and commercial. The Mobile ITS Platform further provides ITS students with a unique mobile laboratory experience and capability, wherein hands-on, real-time opportunities are available with the sensor, communication, and automation technologies.

This project also enabled the modernization and improvement of ITS infrastructure and equipment. It has expanded and improved ITS capabilities from field engineering to data processing and networking. With the assistance of OkTC, the ITS Lab was able to dramatically improve capabilities in traffic engineering and traffic research.

Early impact of this project can readily be seen in the extensive leveraging of this equipment by Oklahoma Transportation Center, Oklahoma Department of Transportation and Oklahoma Highway Safety Office projects. The effectiveness of M-ITS Platform can be seen in the two use case that occurred immediately after this project was completed as described in Section 2.2. However, the impact of this platform is not isolated to the activities in those studies. Server hardware and storage devices are making an impact on improving law enforcement and public safety on a daily basis. Ruggedized computing hardware and improved vehicles get engineers from the ITS Lab to the field and allow them to perform maintenance and set up new experiments on a daily basis. Back-up power generation and improved HVAC resources improve the ITS Lab and ODOT reliability and assist in serving the public.

Mobile trailer mounted instrumentation allows ITS Lab engineers to get measurement equipment in the field in rural and non-highway environments and expands the research areas for the lab. Experimentation has been expanded into areas that were inaccessible for the ITS Lab before. Continual improvement and vectors of data integration and exploitation is a core focus of the lab and this project has expanded the scope and depth of the abilities to access the lab.

4.2. Recommendations

The ITS Lab at OU will continue to seek to improve the equipment and infrastructure and to make an impact in the state of Oklahoma. A plan for maintaining the purchased equipment for its expected life was included in the original proposal for this project. A five year technology plan should be developed that includes replacements and upgraded server, networking, and storage equipment as necessary.

A ten year plan should be drawn up for replacement of ITS Lab vehicles and portable trailer equipment. Special focus in both plans.should include leveraging multiple funding sources to overcome the large amount of monetary resources that will be required to replace equipment after its useful life.

4.3. Future Work

The ITS Lab will continue to focus on improving research and support of ITS equipment and the ODOT network. Due to the mild winter of 2012-2013 data collection for weather data related research was limited. Future research into the effects and duration of salt and chemical de-icing and physical snow removal in the coming year will have a significant impact.

The ITS Lab will continue to improve its traffic flow estimation techniques and in particular to apply those techniques to the travel time estimation problem.

Continued development of police software and automation to improve the accuracy and timeliness of citation and ticketing systems is a central focus of the ITS Lab and this will be an area of future work as well.

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