PROTOTYPING AND TESTING OF A FULLY AUTONOMOUS ROAD CONSTRUCTION BEACON, THE ICONE®

Prepared for

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A revolutionary portable traffic monitoring device is developed, extensively prototyped and thoroughly tested throughout the State of New York as well as several other states. The resulting device, trademarked as the iCone®, simplifies the process of traffic monitoring to the point where the entire process of data collection, transmission, and distribution is executed at the flip of a single switch. The iterative prototyping and testing process is centered around a public/private partnership including iCone Products LLC (iPL), the Calmar companies, the Federal Highway Administration (FHWA), the New York State Energy Research and Development Authority (NYSERDA), and the New York State Department of Transportation (NYSDOT) and eventually involves departments of transportation from several states and expands to include participation from law enforcement, contractors, and private sector traffic information services. The highly inclusive nature of the test program led to a solution that addresses needs in traffic information, construction management, and law enforcement. The overall program has launched a new corporation and a new product that is in regular use in six states.</td></tr>
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ABSTRACT

A revolutionary portable traffic monitoring device is developed, extensively prototyped and thoroughly tested throughout the State of New York as well as several other states. The resulting device, trademarked as the iCone®, simplifies the process of traffic monitoring to the point where the entire process of data collection, transmission, and distribution is executed at the flip of a single switch. The iterative prototyping and testing process is centered around a public/private partnership including iCone Products LLC (iPL), the Calmar companies, the Federal Highway Administration (FHWA), the New York State Energy Research and Development Authority (NYSERDA), and the New York State Department of Transportation (NYSDOT) and eventually involves departments of transportation from several states and expands to include participation from law enforcement, contractors, and private sector traffic information services. The highly inclusive nature of the test program led to a solution that addresses needs in traffic information, construction management, and law enforcement. The overall program has launched a new corporation and a new product that is in regular use in six states.

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SUMMARY

iCone Products LLC (iPL) and its partner Calmar companies have completed a twenty-six month effort to construct and build a highway construction beacon, trademarked as iCone®. The resulting device meets the original program goal of providing a very-highly deployable monitoring system that allows any worker to establish speed monitoring in a highway work-zone. The system allows all stakeholders, engineers, law enforcement, and construction supervisors, real-time access to speed and vehicle count data without coordination from information technology (IT) staff.

In this program iPL, the New York State Department of Transportation (NYSDOT), and the New York State Thruway Authority (NYSTA) participated in field tests. Direct comparisons with legacy sensors were performed and the iCones were deployed in more than ten work-zones in 2008. The strengths and weakness of the device have been noted and now the iCone® is being recognized across the country as a revolutionary capability and the joint iPL/NYSERDA/NYSDOT/FHWA program as an example of a successful private/public partnership.

1.0 DISCUSSION

The Calmar companies, including subsidiary iPL, in partnership with Telematics Services, undertook a project to arrive at a fully automatic road construction beacon that can be easily used to mark and remotely monitor roadwork. The device, trademarked as the iCone®, advanced the proposition that roadwork can be easily and quickly monitored with the careful integration of existing technologies. Prior to this development effort, the location of existing highway construction activities was generally not well identified to the motorists and traffic conditions within these work-zones were seldom monitored in a manner that could be used by motorists preventing informed decision making by the traveling public. Additionally, the lack any information on traffic conditions in work-zones also has encumbered the relevant highway agency's efforts to manage traffic in the work-zone.

Traffic delay caused by construction activity is estimated to be about 10% of all traffic delays encountered by motorists. (Source: http://www.ops.fhwa.dot.gov/aboutus/opstory.htm) These delays cause tens of millions of gallons of fuel to be wasted annually. In addition to the wasted fuel consumption, work zone delays are also a major cause of decreased productivity and motorist frustration. When the frustration of motorists builds to a breaking point delays create safety issues to the motorists and roadside workers alike. All aspects of our society are affected; emergency response services are encumbered when vehicles are also caught in traffic backups, and family time is lost waiting in back-ups on the way home.

Until the advent of the iCone®, the only readily available method to monitor work zone traffic conditions entailed the use of trailer mounted sensors. Compared to the iCone® the trailer based platforms are found to be difficult to deploy and much more difficult to setup. Their trailer based platform prevents deployment at many locations creating their own hazard to traffic. Even when deployed, the data gathered by them is often handled in a manner that prevents its distribution to stakeholders. With no unified mechanism present to provide the information to the highway agency and the highway user the data from these systems in real-time is of little value. One of the most unexpected results of offering the iCone® is the appreciation expressed by engineers in being able to simply extract the data that they need from the web application.

The goal of the iCone® development team was to create a traffic sensor system that is autonomous enough, flexible enough, and economical enough to make it reasonable to expect everyone working on the highway to be able to deploy and integrate the Intelligent Transportation System (ITS). In order to do this it was necessary for the iCone® team to address these issues by developing a work zone traffic monitoring tool that has the following attributes:

- **Highly portable.** A single person in a pickup truck or panel van can deploy the iCone®;

- **Ease of deployment.** The iCone® is self calibrating, requiring no skilled technician to set up. Its small footprint (roughly 2 feet by 2 feet) allows it to be placed at most locations available on the roadside;

- **Communicates from anywhere.** Due to the fact that cellular communications will and continue to have in the foreseeable future locations without cellular coverage, iCone® has satellite communications with the Iridium Satellite service. Iridium claims to have 99.4% reliable coverage though out North America.

- **Ease of System Integration.** This was accomplished by developing a fully functional web based reporting and device control interface that fully functions with most web browsers. Additionally, streaming device feeds at the data layer is available for direct integration into existing traffic operation center's software. This effectively provides the highway agency a turnkey solution for temporary traffic monitoring needs that integrates directly into their management processes.

This project developed the aforementioned attributes for a traffic monitoring tool from scratch. While off-the-shelf technology was used throughout this project, design through system integration was the means by which the program goals were reached. This required significant engineering via a design through testing feedback loop process.

Beyond the physical device, the significant back office computer software development occurred. The purpose of the software development process was to address the need to provide a turnkey interface with the user at any location the user may be regardless of knowledge of the activities of the person who deployed the device. The provision of an internet based (thin client) solution avoided many issues. These issues include a variety of complex systems already installed at many agencies (traffic operation center software), stand alone software support that accompany desktop installations among differing computers and ease continued software evolution.

The result is a highly functional tool that has drawn national attention. Beyond New York, iCones are now being used in the following states: California, North Carolina, Minnesota, Washington, Montana, Maryland, Vermont and Texas.

DEVICE DESIGN

The iCone® is a traffic monitoring device that was designed from scratch using off the shelf components manufactured by other suppliers. The purpose of this design approach is to use available components that have extensive engineering already completed while not becoming so tightly integrated to a single component as to become captive to the continued availability of components. These concepts lead to a modular design approach, accomplishing this longer term strategic positioning, but also permitted individual component testing during the prototyping process. See Figure 1, below:

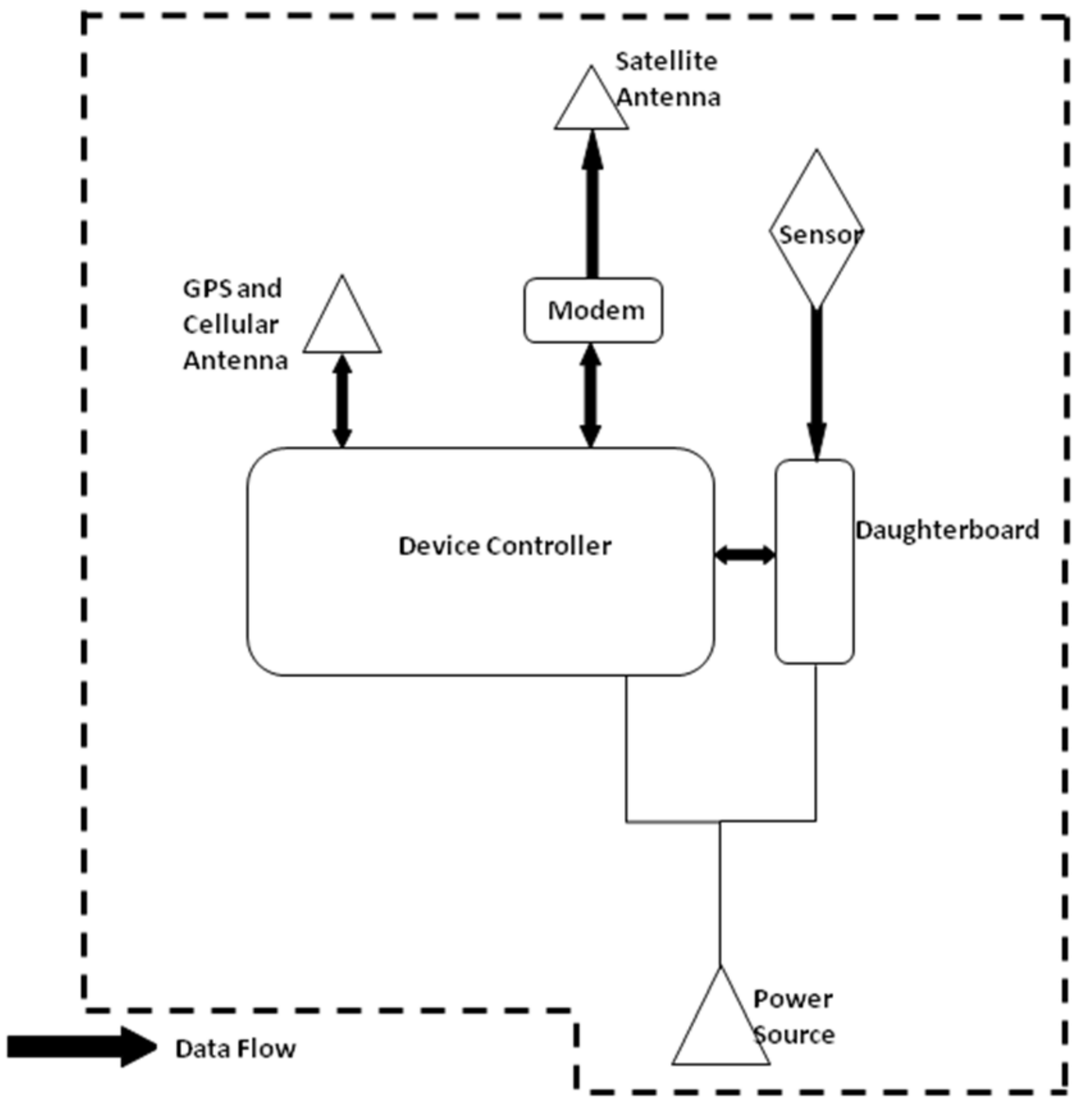


Figure 1. iCone® System Model

As can be seen within the illustration, the modular component approach resulted in a systems engineering effort. Each component was carefully selected and tested during the effort. As a result, some initial components were subsequently replaced with an alternative, as unsatisfactory performance was encountered during the testing process.

The components, while ready to use products in and of their own right, required significant understanding concerning their operational parameters for integration purposes. These components are not consumer products, but system components that are manufactured and sold to businesses who are manufacturing unique products for consumer use.

While Figure 1 provides a basic schematic of iCone's general design, it does not convey to the reader a sense of the iCone®'s assembly. Refer to Figure 2 concerning how the iCone® is assembled in a final production version. The remainder of this section will discuss how the various components were selected, including their evolution during the design process.

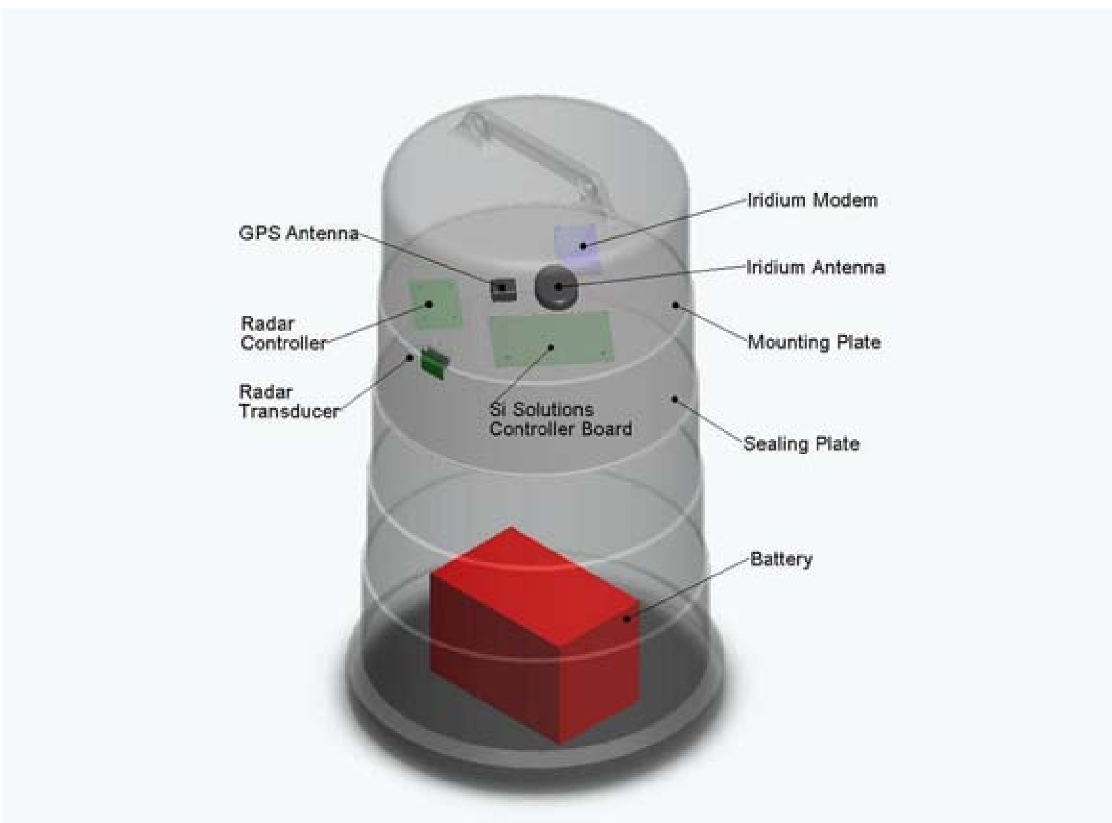


Figure 2. iCone® Assembly

During the system design process, it was very important to balance modularity with the fact that modern electronics have many devices integrated into them. For example, the team selected a device controller that had Global Positioning System (GPS) and cellular phone connectivity integrated into it. In the past, these subsystems may have been stand alone components. However, the state of the practice has evolved to the point that cellular and GPS functionality is tightly integrated into many devices and the advantages garnered by keeping them as individual components are questionable when power consumption and efficient system operations are considered.

Component Selection

The components selected for use within the iCone® were chosen for their initial potential suitability for intended purpose. Referring to Figure 1, the following will discuss concepts applied and experience garnered during the selection and testing process.

Device Controller.

The device controller represents the heart of what differentiates between a traffic barrel and an intelligent transportation systems device. As implied it is "smart" in the fact this component is essentially the equivalent in capability to a laptop computer. The computer chosen is a general purpose computer used for instrumentation control and monitoring purposes. Borrowed from the vehicle telematics industry, it is hardened for extreme temperatures and it contains a number of input/output ports and is preconfigured with geo-positioning capabilities. This particular controller also had the advantage of also being configured for coupling to modems for satellite communications.

Two controller boards from different manufacturers were selected for evaluation. One controller board failed to live up to expectations, as it behaved in an unstable manner. Nominally, it worked, but had sufficient internal instabilities as to cause it to be not selected for progression into the final product. As a lesson learned, CPU devices at this component level are not as standardized as one may expect from assembling a PC from components alone. The incompatibilities and/or lack of stable operation are analogous with the evolution state PCs had reached during the mid 1980s. During that period it was important to know which brands of PCs were compatible with which version of DOS operating software (which many manufacturers had their own version thereof).

The controller selected for final use within the iCone offered the benefits of having an installed operating system (Windows CE) that is widely used, appropriate input/output ports and stable operation. iCone® specific programming is installed on the processor and is stored in non-volatile memory. When the board is energized, it boots the Windows CE operating system and then loads the iCone® specific operations transforming it from a general purpose computer into an iCone®.

During the iCone®'s evolution the controller underwent three design changes. The first product was the existing off the shelf design. It worked well and is within iCone® units titled as Version 1.0 (generally serial numbers NY1107…). Due to a number of unused components within the controller board, its power consumption was a relatively high 450 mW. Power was being expended to simply energize components that were not being utilized for the iCone®'s needs. The resulting battery life of the unit of Version 1.0 units averages to about seven days.

The second version of the iCone®'s controller evolution is titled as Version 1.5 (generally serial numbers NY1207…). This controller is a version 1.0 controller with all superfluous electronics removed, while not changing the circuit board layout. The premise behind this change is to remove unused electronics that are consuming power for the fact that they are being energized. Removing the unused electronics reduced the controller board's power consumption to 300 mW and resulted in a twelve to fourteen day iCone® battery life.

The third and final version of the iCone's controller evolution under NYSERDA's sponsorship is titled Version 2.0 (generally serial numbers NY0208… and beyond). Using lessons learned from the first two iCone® controller board versions, the controller board was optimized for the needed functionality. This was done as a partnership between iPL and the manufacturer, where the manufacturer absorbed the cost to optimize the board. The manufacturer identified the fundamental improvements within the controller as being a product line in and of its self and created a new product for their general sales.

This design optimization resulted in a controller board power consumption of 200 mW. This was achieved by optimizing the board version 1.5 circuit design and placing a dual processor unit on the board. The primary process and most circuits are placed into a sleep mode until communications or other complex sub functions, such as obtaining a GPS position, are required. The secondary processor, a much lower powered one, remains active at all times and, essentially serving as the master processor for the controller board. Other improvements included peripheral interface power supply improvements to better match voltage requirements outboard devices require.

The Version 2.5 board improvements resulted in extending the iCone®'s battery life as long as 21 days, with functional life being 17 days. The 100 mW improvement between versions 1.5 and 2.0 boards might imply that the iCone®'s battery life should have been extended to 24 days or longer. This did not happen because other system components power demand had not changed. In essence, the controller board was no longer the controlling power consumer. In fact, it will continue to report the iCone®'s GPS position when other components fail to operate due to low power and will continue to the point that damage to the iCone®'s battery occurs. Due to this, low power sensing logic was placed into the board's software to force the controller board to enter into a very low power "sleep" mode when battery voltages reach below 10.5 volts. See Figure 3 for the Version 2.5 motherboard (with daughterboard attached).

Daughterboard.

The daughter board is the circuitry that makes iCone® a sensing device. It is the only piece of custom electronics that was developed in the course of the iCone® project. Connected to the controller board via RS-232 communications, the daughter board serves as the interface between the sensor and the controller board. The sensor is a fundamental piece of electronics with limited sophistication and requires a controller to intelligently operate the device in the manner that can be managed by the iCone®'s primary controller board.

The logic behind this design approach is to isolate device evolution to a relatively simple piece of electronics and avoid tightly integrating the sensor to the primary controller. The advantages are many. First, the primary controller is a highly engineered and very sophisticated general purpose computer. Modifying its design creates uncertainty that errors (e.g. "bugs") will not be introduced into the logic behind the operation of the electronics. A daughterboard design also permits an alternative primary controller to be introduced, creating the fundamental advantage that iCone® is not captive to single device manufacturer continued viability or support of a specific product. See Figure 3 for the actual motherboard and daughterboard assembly.

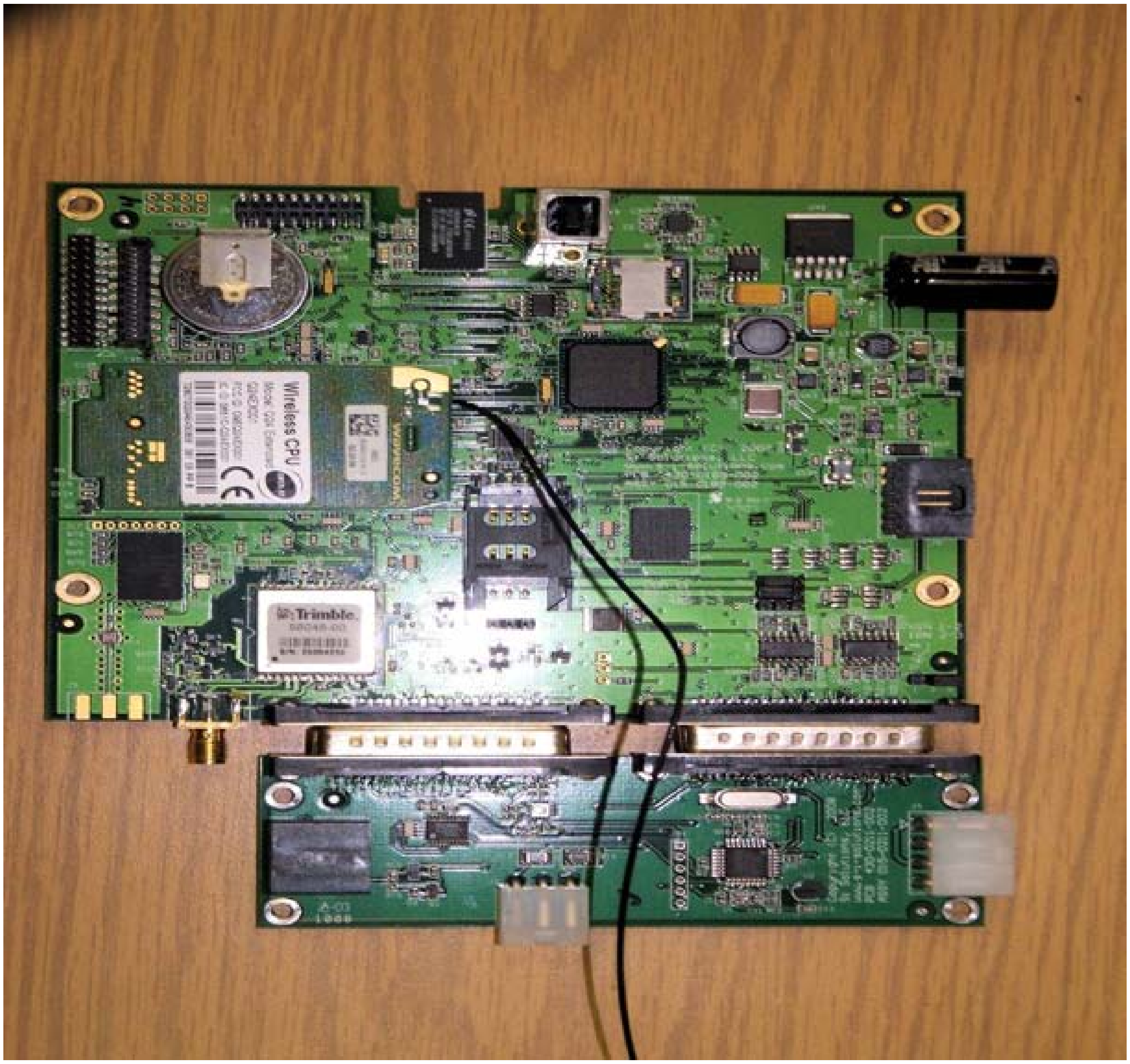


Figure 3. Motherboard and Daughterboard Assembly

Finally, this design approach allows the overall iCone® product line to evolve in an inexpensive manner. As improvements are arrived at or, even, new sensor types are brought into play, the primary controller board does not require re-engineering and extensive testing. The electronics and underlying logic that drives the daughterboard's electronics is relatively simple and involves straightforward engineering. Therefore, future device improvements and capability expansion will remain relatively inexpensive to accomplish.

Sensor.

Sensor selection for the iCone® followed a process of evaluating various traffic sensor technologies, while holding the following general criteria as constants. While the original project proposal suggested using radar technology, it was felt that a due diligence exercise should be performed to confirm the original suggestion was correct.

Criteria

- Non Intrusive – does not involve in/on pavement installation;
- Low Maintenance – use and forget, no cleaning etc.;
- Accurate – meets generally held accuracy criteria from various tests;
- Ease of Set Up – little or no calibration through direct human interaction;
- Proven Technology – used by various highway agencies over time;
- Stand Alone (no peripheral equipment) – no reflectors, external sensors;
- Low Power Consumption – for permanent installs, use 60 watt or less solar panel for continued reliable operation.

The results of the sensor evaluation are provided in Table 1 below:

TECHNOLOGY	**Non Intrusive**	**Low Maintain**	**Accurate**	**Set Up Ease**	**Proven**	**Stand Alone**	**Low Power**
Inductance Loops	N	Y	Y	N	Y	N	Y
Magnetometers	N	Y	Y	S	Y	N	Y
Video	Y	N	S	N	S	Y	N
Infrared	Y	N	Y	N	N	Y	N
RADAR	Y	Y	Y	Y	Y	Y	Y
Sonic	Y	Y	S	N	Y	Y	Y
Laser	Y	N	Y	Y	Y	Y	N
Infrared Beam	Y	N	Y	Y	S	N	N
KEY: Y – Generally the case; N – Seldom the case; S – Sometimes the case (under specific circumstances).							

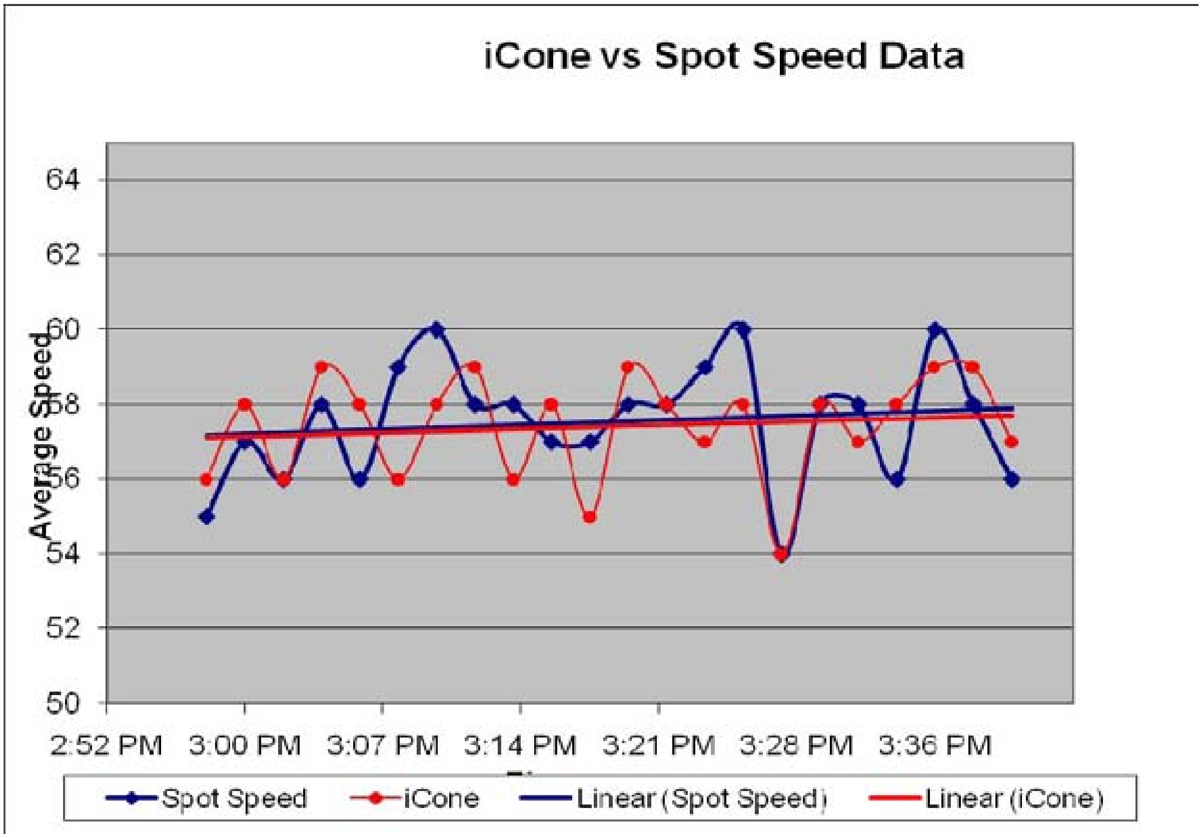
Table 1. Sensor Evaluation

This evaluation was performed via a review of the various traffic sensor technology comparisons published between 2000 and 2007.

As indicated in Table 1, radar was confirmed as the most promising technology to use for the “drop & forget; reuse again with little effort” paradigm followed by Calmar Telematics within the iCone® project. Therefore, the team settled upon radar technology as the iCone®’s primary sensing source.

The selected radar is a 10.125 GHz technology (X-Band) radar that will accurately detect vehicles from a distance as far away as 250 ft. The transducer uses a solid state patch antenna that has a 17 degree horizontal beam width. Its power consumption is 60 mW, which is one of the lowest power consuming radars commercially available for the purposes that iCone® is being used for.

Field trials of the iCone® (discussed more fully in Section 2.0) reveal that the radar assembly within iCone® is an accurate traffic monitoring device. While a number of comparisons have been made by the iCone® team, the team is of the opinion that Figure 4 is most indicative of the radar's accuracy. It was performed by an independent organization (the Oregon Bridge Delivery Partners) during 5/13/2008 using a LIDAR as means to independently validate the radar's speed monitoring capabilities.



Test Performed by the Oregon Bridge Delivery Partners

Figure 4. LIDAR verses iCone®

To elaborate, commercially available LIDAR technology is almost exclusively used for law enforcement activity, as its accuracy is considered to meet legal evidence requirements as an alternative to radar. The New York State Police Troop T, exclusively patrolling the New York State Thruway, exclusively uses LIDARs in lieu of radar for speed enforcement activities.

The project team has obtained similar results with its own testing, however, a certain amount of credibility loss is recognized when an organization tests its own product. The results in Figure 4 were shared with Calmar from a wholly independent organization doing the tests as part of their own due diligence activity.

Satellite Communications.

Referring to Figure 1, the components shown as “Modem” and “Satellite” antenna represent the heart of the “communicate from anywhere” capabilities that iCone® possess. A design requirement by NYSERDA and the NYSDOT is that the iCone® must communicate from most anywhere that it is deployed. This design requirement has been substantiated through experience which has showed that more than 5% of deployments to date have required satellite communications. The ‘works everywhere’ requirement ruled out the use of short range communication technologies, such as spread spectrum radio and implied that the technology must meet broad area communications requirements.

To date, only two off the shelf technologies are established as being reliably available for broad area communications, cellular telephone, and satellite.

To meet the NYSERDA and NYSDOT “communicate from anywhere” design requirement satellite communications were selected for use within the iCone®. The reason is that cellular communications have many places present that are not available. In general, satellite communications have a reliable global reach.

The Orbcomm satellite communications service was initially selected as the communications provider. Through extensive testing, the communications service proved to be unsatisfactory for iCone®’s needs. Reasons primarily centered upon the theoretical data rate limit of the frequency and the message sizes required for iCone®. The result was a too tight fit on message size and a too thin coverage by the satellite network. Concerning the latter, experience showed that coverage gaps were generally as long as 20 minutes and, sometimes, much greater.

The Iridium satellite communications service was subsequently selected for a network and spectrum that promised significantly higher reliability. The change of satellite networks required an account change over, modem and antenna change outs were required, and alterations to the controlling software as these two communication systems inherently operate differently; including their use of different radio frequencies. The Iridium satellite communications service has proved to be very satisfactory for the specified requirement of “communicate from anywhere.”

GPS and Cellular Antenna.

The presence of the GPS and cellular telephone antenna is a reflection of the design philosophy of balancing modularity and the benefits of system integration. The selected controller board has integrated GPS capability and cellular phone communications. However, the design team decided that the integrated antennas were unsuitable for iCone®'s needs. To wit, it selected a superior antenna system that incorporated the needs of either technology.

While GPS technology is fundamental with how iCone® operates as a useful tool to the end user, the project team seized upon cellular communications as a means to make iCone® a tool that is more affordable to the end user. The cost of transmitting data is a major component of the operational costs of the iCone®. By designing in the ability of the device to switch between cellular and satellite communications the reliability of the system can be balanced with the cost of operation.

Satellite based communications is inherently expensive, but it provides a "communicate from anywhere" capability and meets the NYSERDA and NYSDOT requirements. To illustrate, Iridium claims an ability to communicate from anywhere within North America 99.4% of the time. The project's team experience with iCone® throughout the U.S.A. suggests that there is veracity to the claim.

To hold these design tenants whole, while providing a lowest cost as possible to operate and price for the customer, the project team selected a hybrid approach. When cellular communications are available to the iCone®, it operates in low cost cellular mode. When cellular communications are unavailable, it operates in satellite mode.

The result for the end user is transparent. The end user simply sees the reported data he or she expects. Calmar takes care of what is happening within the communications "cloud," making things transparent to the end user.

Power Source.

The power source selected for iCone® was just as carefully selected by the project team as any other component was. Many battery technologies are available and they have their own operating characteristics. Selected was a lead acid technology. While superficially considered to be "old fashioned" it contains many advantages that newer designs do not. These are as follows:

- -30 degree Celsius to + 40 degree Celsius operating range. The iCone® is an outdoor device whose intent is to operate following an "anywhere, anytime" philosophy. Research into other battery technologies reveals that their operating range generally follows a much narrower, and more temperate, operating temperature range.

- Generally high current storage capability. While considered by many to be "old fashioned," lead acid batteries acquit themselves well in comparison to many more modern battery technologies. However, their energy storage potential is not so high as to make them explosive if suddenly breached. Lithium ion batteries will literally explode if suddenly breached. iCones® must be designed to be hit by errant vehicles, while not creating an explosion in and of themselves when being destroyed by the vehicle hitting it.

- Concerning the latter point, the selected lead acid battery design used within iCone® is that of an Absorbed Glass Mat (AGM) design. While containing the undesirable weight penalty that lead acid batteries have, this battery design has superior properties for application within iCone®.

  First, it is a "dry" design. The acidic electrolyte is absorbed within fiberglass mats, creating a non-spill product. If the iCone® is hit by a vehicle, the road worker does not need to concern him/herself with hazmat protection to clean the debris off of the road.

  Second, this battery type is United States Department of Transportation (USDOT) approved. In essence, this approval is critical for battery use in facilities or transport under the USDOT jurisdiction. This includes deployment on highways. AGM batteries can be air or ground transported without special permitting, which is important from a product delivery and deployment standpoint.

  Third, battery design has a very broad operating range, meaning that the iCone® is inherently reliable throughout a broad environment where traffic monitoring needs are required.

  Finally, the battery design has a relatively broad high energy storage capability, meaning that there will be extended times between necessary recharge maintenance periods.

For amp hours stored, the AGM lead acid battery design is low cost. The battery's primary disadvantage is weight. The project team leveraged this disadvantage into an asset with the fact that the similar weight (50 pounds) is required to secure a roadside traffic barrel onto the highway. Experience by highway agencies indicate that less weight will result in barrels shifting around, including entering into the open driving lanes. The same weight is provided by either sand bags or recycled tire rubber rings placed around a "dumb," non-iCone® traffic barrel.

Table 2 presents characteristics of some of the battery types considered during the design phase. While many batteries have energy storage characteristics higher than AGM lead acid batteries, they do not possess other characteristics that are just as important such as operating well in a wide range of temperature environments. Others are known to explode if violently breached (such as when an iCone® is hit by a vehicle) or are simply unavailable commercially in the power storage quantities needed to service the iCone®.

Battery Type	Power to Weight (W/kg)	Monthly Self Discharge	Cycles	Discharge Memory Effect	Deep Discharge Tolerance	Temperature Tolerance, Shelf Life	Toxicity	Cost	Comment
AGM	180	3%	600	L	VG	G	H	M	Lead Acid Variant
NiCad	150	10%	2000	H	VG	M	VH	H	
Li-Ion	300	7%	1200	L	VG	P, temperature	M	VH	USDOT Restricted
NiMH	500	30%	750	M	G	P, shelf life	M	H	Size Needed Unavailable
Li-Polymer	600	10%	400	L	VG	P, temperature	M	VH	USDOT Restricted
Key: L = Low, M = Moderate, H = High, VP = Very Poor, P = Poor, G = Good, VG = Very Good, M = Moderate, H = High, VH = Very High									

Table 2. Battery Characteristics

<u>Device Housing.</u>

While not considered to be a fundamental system design element, the iCone® housing is very important. First, it protects the electronics from the harsh roadside environment. Additionally, the shape, color, and construction of what can be placed on the roadside is very highly regulated. The regulating authorities involve the USDOT, the individual state highway agencies. Very significant guidance is provided by the American Association of State Highway and Transportation Officials (AASHTO) approved Manual of Traffic Control Devices (MUTCD) to these authorities.

During the early phase of the project, the initial concept was to place the electronics into a traffic cone looking device that borrowed upon European design concepts. This concept was subsequently discarded once it was learned that highway agencies would likely resist the placement of such a looking device on U.S.A. highways. Subsequent conversations revealed the preference for housing the electronics into a standard Type I/III construction barrel.

Figure 5. Type I/III Construction Barrel

While the standard form factor of a Type I/III construction barrel is standard, the state highway agencies often specify considerable differences among the type of plastic the barrel is composed of. Further, there is considerable variation among the striping width, reflective material the stripes are comprised of and the number of required stripes for a barrel must possess.

Some of these stripes are comprised of metallic material and, therefore, the radar placement within the barrel became a design issue. The current production models of the iCone® employ low density polyethylene barrel material that is outfitted with high intensity reflective tape. These material have been found to meet or exceed most state specifications, however, other material is available on a per order basis.

An additional device housing change during the project lay with the placement of a shoe to drag the iCone® upon. It was discovered during device testing that the flat area at the traffic barrel base wore prematurely over periods of premature handling from simply dragging the iCone® around. A shoe consisting of a very high density polymer was developed and fabricated for use on the iCone®. All iCones® are equipped with this shoe. See Figure 6 for two production variants

Four Stripe, 6" Engineering Grade Tape

Four Stripe, 8" High Intensity Grade Tape

Figure 6. iCone® Variants

SOFTWARE CONSIDERATIONS

The aforementioned discussion centered upon the construct of the iCone® proper. This is only "half of the story." While a challenging systems engineering effort in and of itself, the iCone® would be useless without the computer programming that has occurred. The following will discuss the programming that has occurred to transform the iCone® from a "dumb" device into one that is "smart."

Controller Board.

The controller board is a general purpose computer using the Windows CE operating system to function. Without the installation of application level software, the controller board does not perform any other function than boot up when energized. Specific software was prepared to provide basic device functionality with collecting data and to transmit said metrics back to a central server. It provides the following functions:

- Power on, self test of components;
- Test battery power level and communications connectivity;
- Obtains the iCone®'s position via GPS services;
- Loads configuration data for metrics gathering;
- Loads reporting interval periods;
- Collects data and transform them into metrics.

The iCone® is equipped with an external LED to provide to the end user a sense of the device's status. (Figure 7) It was provided as there is no other indication within the device that the device is properly functioning. The iCone® has no end user accessible ports to connect a laptop to, as the provision of such a port may not stand up well in the harsh roadside environment.

Figure 7. Production iCone®

While the internal software of the iCone® is relatively complex incorporating a rule based logic system strengthened by the lessons learned from 18 months of testing, the user interaction has been reduced to a handful of variables in a 'settings file'. The settings file allows the user to adjust the operation of the radar and the scheduling of the various messages. Variables in the settings file include:

Radar messages

- Message Interval – Frequency, in minutes, for a radar message.
- Start Interval – Time, in seconds, between starting radar collection intervals.
- Read Time – Time, in seconds, to leave the radar on for a collection interval.
- Read Delay – Time, in milliseconds, to sleep the radar after a valid read.
- Max Read Count – Maximum number of valid radar reads to accept during a collection interval.
- Standard Message Flag – Whether or not to collect an aggregated radar report message.
- Bin Message Flag – Whether or not to collect a 5 mph radar read bin report message.

GPS location messages

- Message Interval – Frequency, in minutes, for a location message

- Max DOP – Minimum GPS accuracy for a location message (DOP=Dilution of precision; 1=ideal, 1-2=excellent,2-5=Good, 5-10=moderate, 10-20=fair, >20=poor).
- Max Attempt – Time, in minutes, to try to achieve the Max DOP for a location message.

GPRS/Cellular communications

- Message Interval – Frequency, in minutes, between transmissions.
- Fails – Number of transmission failures before Satellite transmission attempt.
- Failure Lock Out – Number of times the Fails counter is allowed to roll over before GPRS transmission is no longer attempted.

Satellite communications

- Message Interval – Frequency, in minutes, between transmissions.
- Message Timeout – Time, in seconds, before an unsuccessful transmission attempt stops.

Temperature messages

- Message Interval – Frequency, in minutes, for a temperature message.

Compass messages

- Message Interval – Frequency, in minutes, for a compass message.

CRASH WORTHINESS TESTING

A key requirement of placing a piece of equipment on a highway right-of-way is the verification that it meets the national standards for safety in the event that a vehicle should hit the equipment. The NYSDOT and the NYSTA both stated that the iCone® must pass the standard set by the National Cooperative Highway Research Program (NCHRP) Report 350 Category 2 as certified by a third party test facility.

The NCHRP 350 Category 2 standard is intended to insure that if a light passenger vehicle should strike a piece of equipment no passenger in the vehicle will be injured. In practice the test requires that a very light passenger car such as a Geo Metro hit the piece of equipment while traveling at 100 kilometers per hour and not change direction by more than 20 degrees and no debris penetrates the passenger compartment.

As part of the development program, iPL hired Calspan of Buffalo, New York to perform the NCHRP testing. Two iCones were placed on the test track, each one aligned with the path of one of the front wheels. The car was drawn up to speed with a cable mechanism and the collision was recorded with accelerometers in the vehicle and four high speed cameras. The test resulted in very little damage to the vehicle and only a few degrees change in direction.

The entire test report has been filed with both NYSDOT and the FHWA and the FHWA has issued a National Approval letter a copy of which is included in Appendix A.

2.0 FIELD TESTING

During the 2008 testing period the iCone® was field tested in five of NYSDOT's districts and the New York State Thruway Authority (NYSTA) capital region. Some of these tests were performed to establish the accuracy of the iCone® as a speed detector and as a vehicle counter but the majority were performed as work-zone deployments to test the basic concept of very-highly deployable ITS.

Since the beginning of the NYSERDA/NYSDOT testing the iCone® has also been tested in more than 10 states including Oregon, Washington, California, Vermont, North Carolina, and others. This multi-state testing and the national conversation which has resulted should be considered an opportunity to the states, an opportunity to learn from dozens of other professionals and expand the art of work-zone traffic control.

With dozens of deployments preformed during the testing period this report will focus on three unique cases.

NYS Thruway Calibration Tests

In 2008 the New York State Thruway placed iCones® at two constant count stations between Exit 24 and Exit 23 with the intent of establishing the accuracy of the iCone®. In this situation the iCones® were placed off the shoulder in locations where they were protected by guardrails or other existing equipment.

In this case the iCone® was shown to have slightly lower (3mph) speeds than the inductance loop sensors installed in the right-hand (driving) lane of the Thruway and approximately 8 MPH lower speed than the left-hand (passing) lane of the Thruway.

The difference between the iCone® readings and the speeds measured in the passing-lane of the Thruway is a reflection of the iCone's® low profile only allowing its radar to primarily sense vehicles in the nearest lane. At medium to high volumes of traffic the second lane is not visible to the iCone® and requires a second iCone® on the median to measure left-hand lane. Therefore an iCone® set on the right shoulder will primarily be measuring the speed of vehicles in the slower driving-lane and shouldn't be expected to reflect the passing-lane speeds.

The comparisons between the iCone® and the inductance loop sensors in the driving-lane were much more favorable with the iCone® speeds registering 3-4 MPH lower. Even so, this difference is noticeably higher than seen in other direct comparisons which have shown the iCone® to return speeds within 2 MPH of loop detectors. iPL believes the discrepancy in speed in this case is due to what is known as the 'cosine error'. The cosine error is the error that is realized when a sensor measures the speed through an observation that is not in line with the direction of travel (Figure 9). In this case the error represents the fact that the off-center device is only measuring the component of speed that is along the line that directly connects the device and the vehicle. The speed along this line is less than the actual speed of the vehicle by the cosine of the angle at which the device sees the vehicle. In other words, the farther the device is from the lane of traffic, the bigger the error. In the case of the NYSTA test the iCone® was more than 15 feet from the driving-lane. One conclusion that can be taken on speed measurements with the iCone® is that placing the iCone® more than 10 feet from the lane of traffic will begin to result in speed errors of 3%-5%.

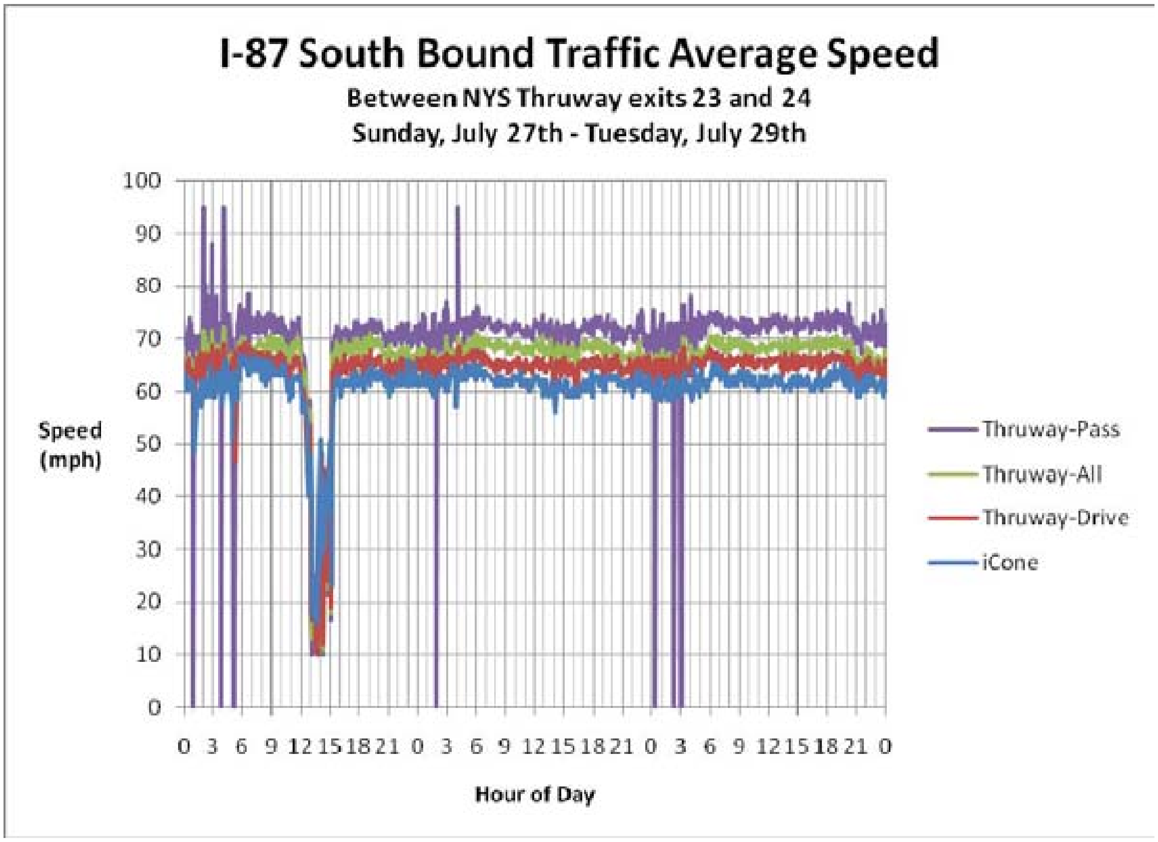


Figure 8. Speed Comparisons on NYSTA

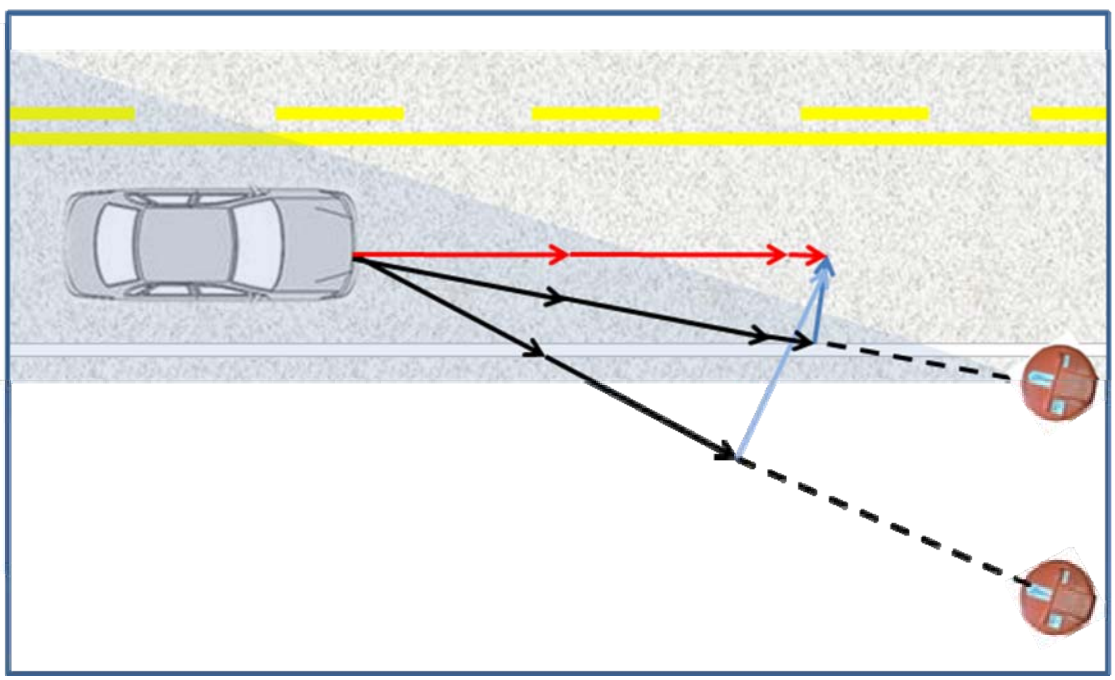


Figure 9. Cosine Error Diagram

While the iCone® was not initially intended for counting vehicles, the capability would be highly valued. The primary difficulty is that the demand to make the iCone® highly portable necessarily results in a small package and, therefore, the iCone® can not see over vehicles and can't count vehicles in the far lane when traffic volumes are heavy.

At the constant count site on the NYSTA the iCones® were used to record vehicle counts and these counts were compared to the loop detectors. The results of this comparison shows that the iCone® generally counts a combination of the volume in the near and far lanes, slightly more than either one, and at medium to low volumes the equivalent of the two lanes combined (Figure 10).

In this and other tests it has been concluded that the iCone® is a reasonable tool to ascertain the qualitative volume of the traffic flow and those volumes are reasonably accurate for moderate to low capacity flow. It must also be concluded that the iCone® as a 40 inch tall device can not reasonably count traffic on multi-lane roads when the flow is saturated to the point where vehicles in the far lane are obscurred by vehicles in the near lane.

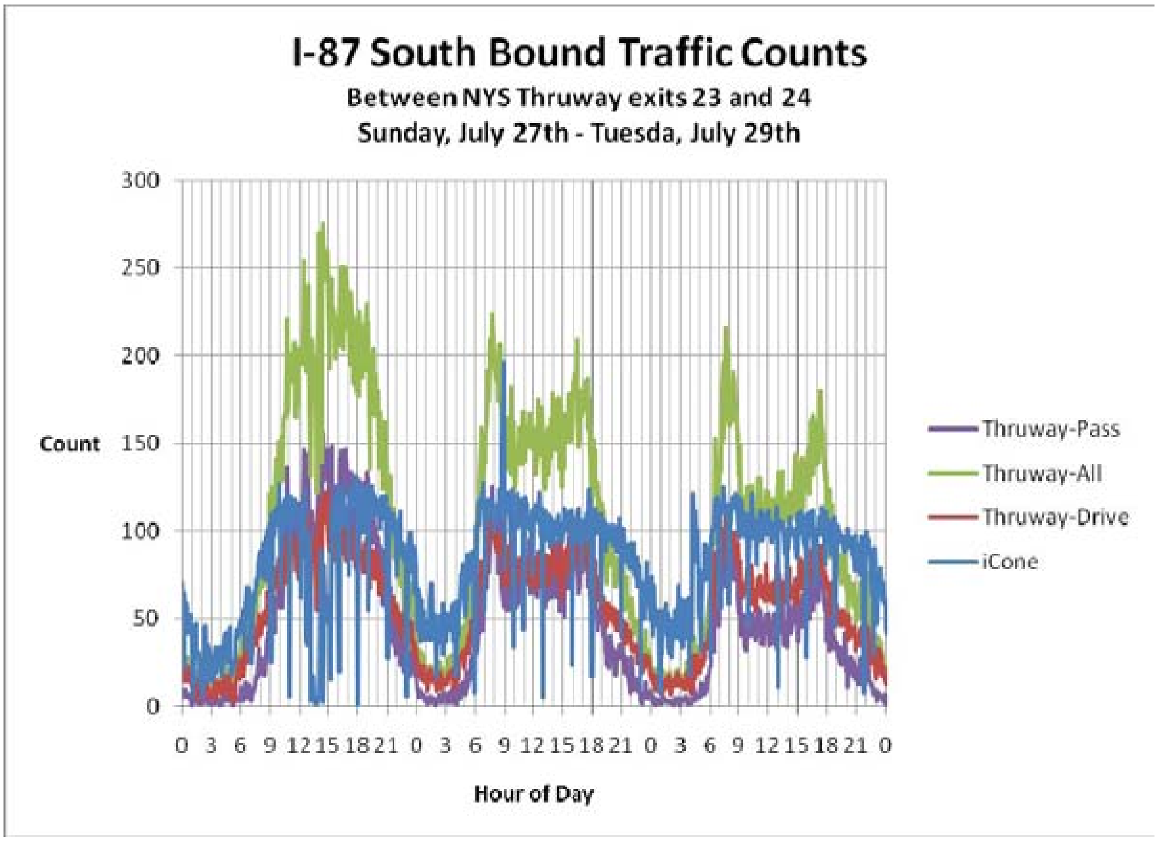


Figure 10. Vehicle Count Comparisons on NYSTA

I-690/Hiawatha Bridge Replacement

The first significant work-zone deployment of the iCone® was in NYSDOT Region 3 on an interstate bridge replacement project which remained active through 2007 and 2008. This highway project entailed the replacement of a bridge on I-690 in Syracuse.

In 2007 the bridge on the westbound side of the highway were completed. In December of 2007 iCones® were deployed as the project converted to work on the eastbound lanes. At this time eastbound traffic was crossed into the west bound lanes for more than six months. This location has a moderate inbound congestion event each day. To measure the queuing effect iCones® were placed at approximate quarter mile intervals from the beginning of the taper at location #4 (Figure 11) upstream a total of ¾ of a mile. A fifth iCone® was placed ½ downstream at the point where the crossover had been accomplished.

In this first deployment iPL was primarily interested in getting the iCones® into the field and getting feedback from the engineer in charge (EIC) and the state police. iCones® were kept active on this site from December 2007 through April 2008.

During this deployment the Version 1.0 iCones that were used were noted to have a battery life of approximately seven days. Actual experience managing and recharging the iCones® demonstrated that the seven day battery life resulted in an unacceptable amount of labor. The Version 2.0 iCones® deployed on the same job proved to have a much more acceptable battery life of 12-14 days.

This first deployment also demonstrated that viewing the iCones® on the web page did not always result in the same interpretation of the layout as actually being on the site. As a result iPL will necessarily be adding interpretive cues to the website in the coming year. Some of these cues will include things like marking the iCones in the queue before the work-zone differently than the iCones in the work-zone, marking the beginning of the taper, and marking the location of message boards.

iPL placed iCones® at 500 foot intervals in advance of the work-zone and was able to clearly pick up the expansion and shrinkage of the queue with the morning rush. These iCones® were set to report radar readings on a faster two minute cycle allowing for the detailed monitoring of the queue position. iPL was able to record and report on a very precise record of the queue position as well as an accurate calculation of both the travel time and the delay through the work-zone, three of the metrics which are widely being considered as standard metrics for the new FHWA work-zone rules.

Figure 11. I-690/Hiawatha Bridge Project - Webpage

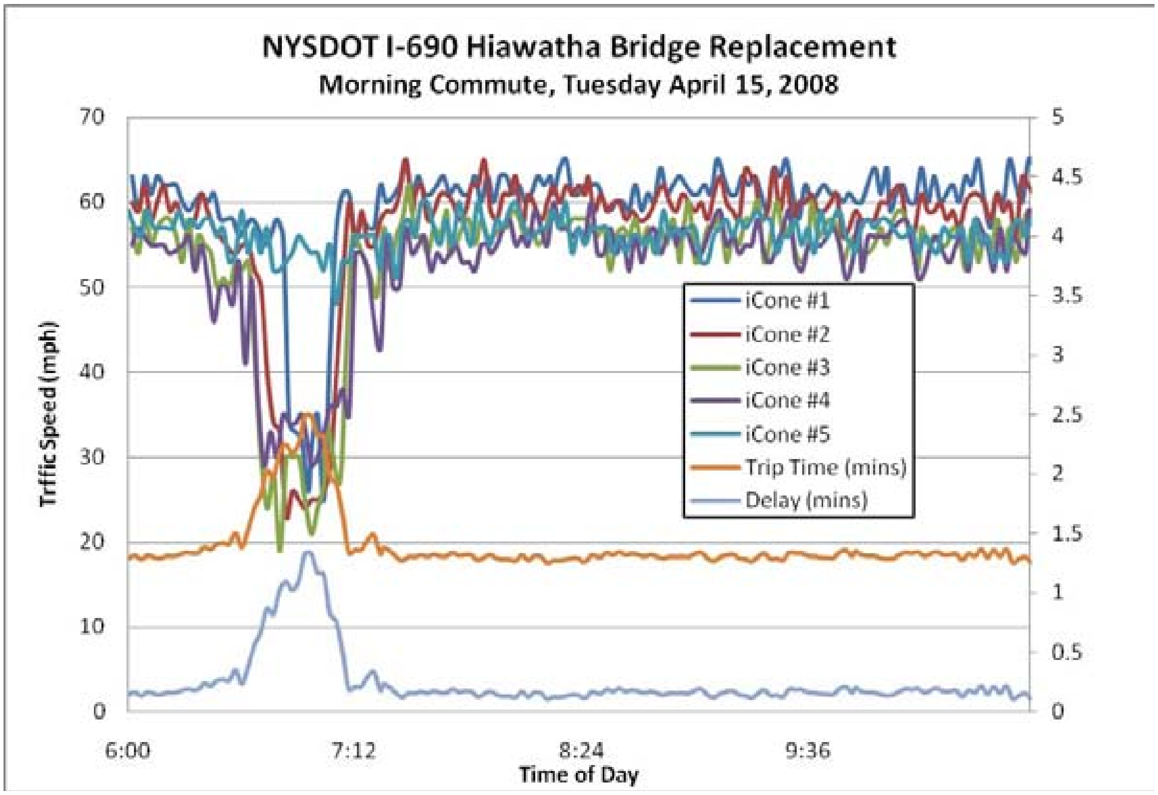


Figure 12. I-690/Hiawatha Bridge Project – Travel Time/Delay

NY State Fair Temporary ITS Deployment

In August of 2008 the NYSDOT asked iPL to deploy iCones® on the roads around the New York State Fair in order to demonstrate the ability to create a temporary ITS network for a temporary event.

iPL deployed a total of 20 iCones® in a period of four hours. The bulk of this time was spent travelling to and from the iPL office to due to the small truck that was used. iPL anticipates that similar deployment might generally be executed by two people at a rate of 10 iCones® per hour.

During this event I-690, which is the primary road passing in front of the Fairgrounds was monitored with the NYSDOT Traffic Management Center's (TMC) camera system. The iCones® were specifically deployed on ramps and roads that were not well monitored by the TMC's equipment. The TMC, State Fair officials, and local radio traffic professionals were acquainted with the iCone® web application with the agreement to experiment with how a speed based temporary traffic network might be used.

At 11:00AM on the first morning of the 21st of August, the first day of the Fair, a roll-back dumpster truck struck a pedestrian bridge approximately one mile west of the Fairgrounds on I-690. This accident resulted in a number of severe injuries but it also shut down the primary highway feeding the Fair. Immediately after the accident happened iPL contacted the traffic professionals at the radio stations to confirm that the iCones® were positioned appropriately to handle the situation. iPL also attempted to reach the TMC personnel but were unable to due to the extreme activity in the NYSDOT control center.

The first day of the 2008 State Fair has become a historic example of the handling of a major traffic incident during a large temporary traffic event. Even in 2009 it is difficult to say exactly what the conclusions from this event might be. However, we can say that the NYSDOT, the State Police and other agencies did an admirable job in handling the event reopening the highway before the following morning rush. Noted from the experience was that the iCones®, being temporary in nature, filled in the blind spots on secondary roads which couldn't be covered with permanent ITS. The NYSDOT TMC personnel and the radio traffic personnel both reported using the iCone® web application to provide insight into the conditions on the secondary routes.

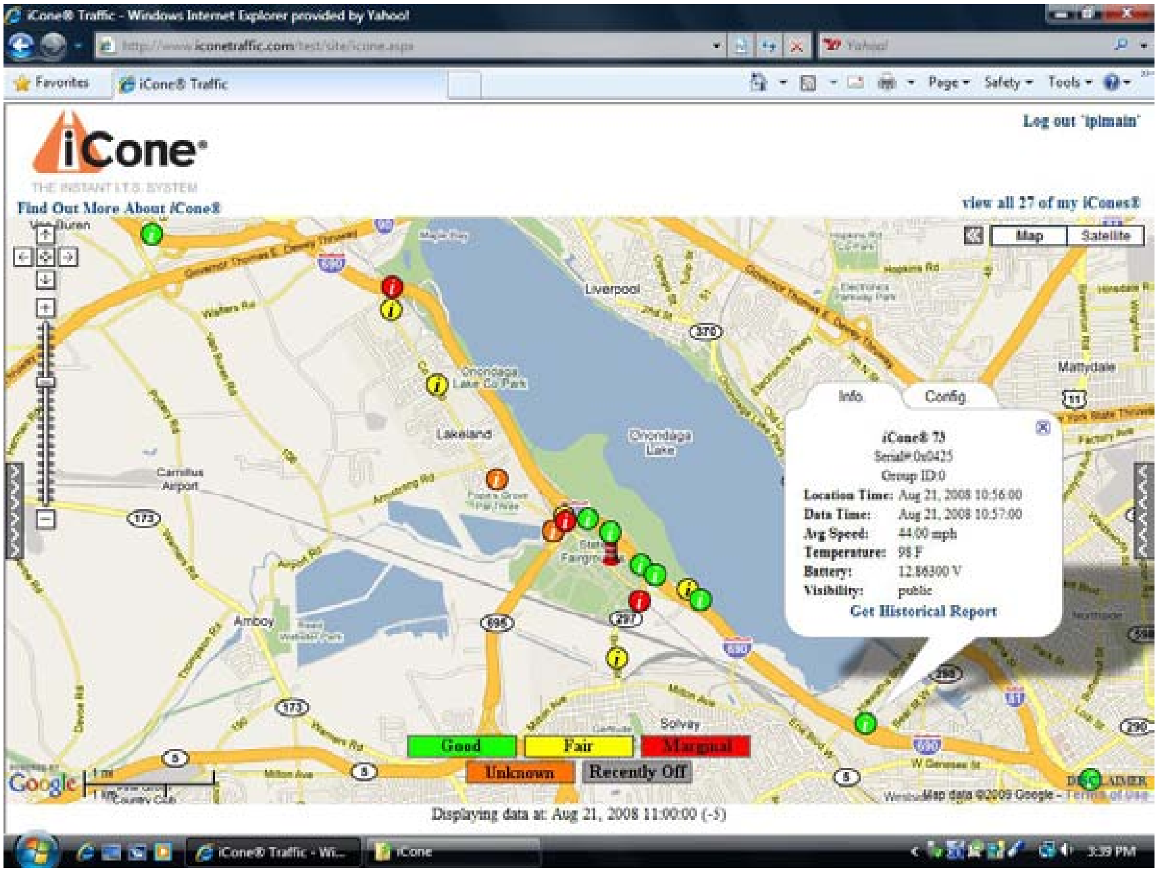


Figure 13. New York State Fair Temporary ITS Deployment – Webpage

Like many other participants in this event conclusions are still being gleaned from the data. However, iPL has concluded that the iCone® has a very significant value to be realized through setting up traffic management capabilities for temporary events.

Since the New York State Fair the iCone® has been used to provide temporary traffic monitoring for the 2009 San Francisco Bay Bridge Closure and for the September 2009 NASCAR race at the Atlanta Motor Speedway. iPL expects that supporting temporary events will become a major role for the iCone® in the coming years.

3.0 SUMMARY AND CONCLUSIONS

This report is being finalized two years after the first iCones® were placed in the field which allows a bit of perspective in the review of the program and the resulting product. At this point iCone Products and its parent Calmar Holdings can firmly state that the iCone® is a success.

The initial technical goals have been met; provide simple, remote speed monitoring in work-zones by transportation and law enforcement staff on every road in New York and at a price that allows broad adoption. Furthermore, iPL has demonstrated that the utility of the iCone® allows state engineers to use the system to meet new rules on work-zone traffic data collection.

Since the beginning of the NYSERDA iCone field trials the iCone® has been included in two FHWA trials. The iCone® was the only stand-alone technology selected for trials in the SAFE TRIP-21 program tested in both the Bay Area Test-Bed and the I-95 Test-Bed. The iCone® is also undergoing a multi-year trial by the FHWA Western Federal Lands department as a speed and travel-time system for extremely remote sites in the National Parks.

Still further, the iCone® is becoming a part of the department of transportation operations in multiple states.

> **California –** Regularly used in the San Francisco Bay area by work-zone traffic inspectors. Used by the City of Pasadena to provide additional ITS for the Rose Bowl and the BCS Bowl.
>
> **North Carolina –** Used in six work-zones in 2009 and becoming part of a new requirement for queue detection in 20% of all work-zones in 2010.
>
> **Vermont –** Anticipated as a requirement for all work-zones in 2010 as a replacement for a patrol car.
>
> **Minnesota –** Finishing trials and expected as a low cost alternative to smart-work-zones allowing monitoring in many more work-zones in 2010.

In summary, the Calmar/iPL/NYSERDA/NYSDOT/FHWA effort to create a new capability for speed enforcement in the work-zone has resulted in a product that is drawing a lot of positive attention from professionals across the country. Beyond the domain of speed enforcement, the ITS and work-zone data communities are expressing appreciation for a program that has allowed leveraging of the investment several times over. For all of these reasons iPL and Calmar feel that this program is an excellent example of the private/public partnership done properly.

APPENDIX A

U.S. Department of Transportation
Federal Highway Administration

1200 New Jersey Avenue, SE.
Washington, DC 20590

May 8, 2008

In Reply Refer To: HSSD/WZ-272

Mr. Robert D. Francis
Telematics Services LLC
1607 Sand Key Estates Ct
Clearwater, Florida 33767

Dear Mr. Francis:

In your letter of April 25 you requested the Federal Highway Administration (FHWA) acceptance of the iCone Intelligent Traffic Beacon as a crashworthy traffic control device for use in work zones on the National Highway System (NHS). Accompanying your letter was the FHWA Office of Safety Design form that included a drawing and a detailed description of the channelizer, a test report, and videos of the crash test. The drawings are enclosed with the acceptance form for the iCone Intelligent Traffic Beacon. You requested that we find these devices acceptable for use on the NHS under the provisions of National Cooperative Highway Research Program Report 350 "Recommended Procedures for the Safety Performance Evaluation of Highway Features".

This letter is the acknowledgement of the FHWA's acceptance of your requests. The original completed forms have been modified by the addition of the FHWA acceptance letter number and the date of our review. The form will be posted on our Web site in the near future.

Sincerely yours,

David A. Nicol, P.E.
Director, Office of Safety Design
Office of Safety

Enclosures

Attachment 1

Page 1	FEDERAL HIGHWAY ADMINISTRATION OFFICE OF SAFETY DESIGN Category 2 Work Zone Device Acceptance Letter	Letter Number WZ-272 Date 5/1/08
Contact Info	Petitioner / Developer Name and Address:	
	Robert D Francis, Managing Partner Telematics Services LLC 620 Old Liverpool Road, Liverpool, NY 13088	
	I herby certify that the device(s) covered by this Acceptance Letter meet(s) the crash – worthiness test and evaluation requirements of the FHWA and NCHRP Report 350.	
Signature	Robert D Francis 2008.04.25 11:23:26 -04'00'	
Telephone #	(315) 579-3519	
Email Address	Bob@TelematicsServices.net	
	Laboratory / Engineer Name and Address David Travale, Senior Staff Engineer Calspan Corporation, P.O. Box 400, Buffalo, NY 14225	
✓	I hereby certify that the testing that supports this Acceptance Letter was conducted in accordance with NCHRP Report 350 guidelines, that the device(s) tested is/are accurately described on this form, and that the test results indicate that the device meets all applicable NCHRP Report 350 evaluation criteria.	
☐	I have evaluated the requested modifications to these devices previously found acceptable by the FHWA in Acceptance Letter WZ-___, and hereby certify that, in my opinion, the modifications do not adversely affect the crash performance of the devices. I also certify that these devices are accurately described on this form.	
Signature		
Telephone #	(716) 631-6920	
Email Address	David.Travale@Calspan.com	
Keywords:		
	Type of Device (See page 3) Drum	
	Composition of Sign or Rail substrate (See Page 3) Extruded Plastic	
	Thickness of substrate (inches): 0.20	
	Height of sign from the ground (inches), if applicable: (See Page 3)	
	Flags and or lights present during test? Indicate number of each: # of flags: 0 # of lights: 0 Weight of lights: 0.00 ea.	
Device Name	iCone Intelligent Traffic Beacon	
Detailed Desc. Of Device, Materials, sizes, Fasteners, Substrates Foundation, Aux. Features Ballast, etc.	(May be attached on separate page(s)) See Appendix C of Calspan Final Report dated 10/30/2007	

Attachment 1

Page 2	FEDERAL HIGHWAY ADMINISTRATION OFFICE OF SAFETY DESIGN Category 2 Work Zone Device Acceptance Letter		Letter Number WZ-272 Date 5/1/08
	Mandatory Attachments		
	Attachment # 1: Test data summary page(s)		
	Attach. #1a	Test # See Calspan	
	Attach. #1b	Test # Final Test	
	Attach. #1c	Test # Report dated	
	Attach. #1d	Test # 10/30/2007	
Alternative	**Attachment # 1:** Description and discussion of modification(s) to crash tested and/or accepted device.		
	Date:		
	Attachment # 2: PDF drawing(s) of device(s)		
	Attach. #2a	Drawing Title:	
		Drawing #:	
	Attach. #2b	Drawing Title:	
		Drawing #:	
	Attach. #2c	Drawing Title:	
		Drawing #:	
	Attach. #2d	Drawing Title:	
		Drawing #:	
	Attach. #2e	Drawing Title:	
		Drawing #:	
	Attach. #2f	Drawing Title:	
		Drawing #:	
	Attach. #2g	Drawing Title:	
		Drawing #:	

Attachment 1

Page 3	FEDERAL HIGHWAY ADMINISTRATION OFFICE OF SAFETY DESIGN Category 2 Work Zone Device Acceptance Letter	Letter Number WZ-272 Date 5/1/08

Please select from the following Keywords for "Type of Device":

Longitudinal Channelizing Barricade
Curb (Curb channelizer system with or without road tubes or other channelizers)
Drum
H-Footprint Sign Stand
X-Footprint Sign Stand
Trailer Mounted Signs (Does not include arrow boards or variable message signs or other Category 4 trailer mounted devices.)
Automated Flagger Device (not trailer mounted)
Tripod Sign Stand
Type I Barricade
Type II Barricade
Type III Barricade
Vertical Panel
Intrusion Detector
Ballast (Action relates to ballast on one or more devices)
Channelizer (Individual units unlike cones, road tubes, or drums)

Please select from the following Keywords for "Sign Substrate":

Roll-up / Fabric (with fiberglass spreaders – aluminum or steel spreaders are not allowed.)
Plywood
Aluminum – Solid
Aluminum – Laminate
Corrugated Plastic
Extruded Plastic
Waffleboard Plastic
Wood / Lumber

Please select from the following Keywords for "Height of Sign":

The distance to the lowest point on the sign is:

Low	12 to 18 inches above the pavement
Mid-A	20 to 24 inches above the pavement
Mid-B	25 to 36 inches above the pavement
Mid-C	37 to 59 inches above the pavement
Tall	60 to 71 inches above the pavement
Oversized	72 inches and taller

Attachment 1

Page 4	FEDERAL HIGHWAY ADMINISTRATION OFFICE OF SAFETY DESIGN	Letter Number WZ-272
	Category 2 Work Zone Device Acceptance Letter	Date
		5/1/08

Please note the following standard provisions that apply to FHWA letters of acceptance:

- Our acceptance is limited to the crashworthiness characteristics of the devices and does not cover their structural features, or conformity with the Manual on Uniform Traffic Control Devices.
- Any changes that may adversely influence the crashworthiness of the device will require a new acceptance letter.
- Should the FHWA discover that the qualification testing was flawed, that in-service performance reveals unacceptable safety problems, or that the device being marketed is significantly different from the version that was crash tested, it reserves the right to modify or revoke its acceptance.
- You will be expected to supply potential users with sufficient information on design and installation requirements to ensure proper performance.
- You will be expected to certify to potential users that the hardware furnished has essentially the same chemistry, mechanical properties, and geometry as that submitted for acceptance, and that they will meet the crashworthiness requirements of FHWA and NCHRP Report 350.
- To prevent misunderstanding by others, this letter of acceptance shall not be reproduced except in full. This letter, and the test documentation upon which this letter is based, is public information. All such letters and documentation may be reviewed at our office upon request.
- If the subject of this letter is a patented device it is considered "proprietary." The use of proprietary work zone traffic control devices in Federal-aid projects is generally of a temporary nature. They are *selected by the contractor* for use as needed and removed upon completion of the project. Under such conditions they can be presumed to meet requirement "a" given below for the use of proprietary products on Federal-aid projects. On the other hand, if proprietary devices are *specified by a highway agency* for use on Federal-aid projects they: (a) must be supplied through competitive bidding with equally suitable unpatented items; (b) the highway agency must certify that they are essential for synchronization with existing highway facilities or that no equally suitable alternative exists or; (c) they must be used for research or for a distinctive type of construction on relatively short sections of road for experimental purposes. Our regulations concerning proprietary products are contained in Title 23, Code of Federal Regulations, Section 635.411, a copy of which is enclosed.
- This Acceptance Letter shall not be construed as authorization or consent by the Federal Highway Administration to use, manufacture, or sell any patented device for which the applicant is not the patent holder. The Acceptance Letter is limited to the crashworthiness characteristics of the candidate device, and the FHWA is neither prepared nor required to become involved in issues concerning patent law. Patent issues, if any, are to be resolved by the applicant.

APPENDIX C

iCone™ Drawings and Description

The iCone™ Intelligent Traffic Beacon, manufactured by Telematics Services LLC, Liverpool, NY 13088, consists of a set of electronics modules and a battery sealed in a standard 36 inch traffic drum as defined in MUTCD Section 6F.58 Channelizing Devices. This drum is manufactured by TrafFix Devices, Inc, San Clemente, CA 92672, and is certified by the manufacturer to meet NCHRP-350 TL-3 crash test criteria.

This drum is designed to use the TrafFix San-Fil base that would normally contain approximately 50 pounds of sand. For the iCone application, this base has been modified to accommodate the EnerSys Genesis XE-60 Valve Regulated Sealed Lead Acid Battery. This battery is 10.85" long x 6.75" wide x 7.12" high and weighs 49.4 pounds. The case is flame retardant to UL94 V-0 standards. All of the sulfuric acid electrolyte is fully absorbed into the glass mat plate separators. It is approved as non-spillable and non-hazardous cargo for ground, sea and air transportation in accordance with US DOT regulation 49 and ICAO & IATA Packing Instruction 806. The battery is firmly attached to the base with a metal hold down bracket that is bolted through the bottom of the San-Fil base. See the photographs on the following pages. The electrical connection between the battery and the electronics modules is fused and fitted with a quick disconnect connector so that it easily separates in the event of a crash that causes the top of the drum to separate from the base.

The Mounting Plate holds the electronic components including the Iridium Satellite Modem, Radar Unit, System Controller, Iridium Antenna and GPS Antenna. The plate itself is made from aluminum to provide mechanical strength as well as electrical properties to increase the efficiency of the antennas.

The sealing plate is held in place by the high strength sealant (3m 5200).

All components for iCone have been selected to provide the optimum performance at the lowest possible weight. The total weight calculation is as follows:

Drum and Base	7.3 pounds
Battery	49.4 pounds
Mounting Plate and electronics	4.8 pounds
Sealing Plate	1.0 pounds
Miscellaneous Hardware	1.4 pounds
Total Weight	63.9 pounds

The drawing below shows the internal placement of iCone components. This mounting plate is held in place by three angle brackets and bolts through the side of the drum. The total weight of the Mounting Plate and all components is approximately 4.8 pounds.

iCone Cutaway View--Side