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A Universal Work Zone Network Device – The NetBox™

Final Report

October 2016

Report Number 16-25

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A Universal Work Zone Network Device – The NetBox™

Final Report

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Joseph D. Tario, PE
Senior Project Manager

Prepared by:

iCone® Products LLC

Cato, New York

Ross D. Sheckler
Managing Partner

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Notice

Abstract

An electronic device is developed to perform generalized networking capability for existing and future highway work zone equipment. The resulting device provides the same level of multi-mode communications and networking capability as the iCone®, a NYSERDA sponsored autonomous traffic speed monitoring device. The circuitry is designed, built and tested. The equipment is implemented for basic networking as a speed sensor and a motion sensor in extensive field trials.

Keywords

Traffic, iCone®, DSRC, Work Zone, PCMS

Acknowledgements

The members of iCone® Products LLC would like to thank NYSERDA, the Texas Transportation Institute, and the many state departments of transportation for continued support of the concepts and products which we are striving to bring to market.

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Acronyms and Abbreviations

DSRC	Dedicated Short Range Communications
FAP	Flashing Arrow Panel
iPL	iCone® Products LLC
ITS	Intelligent Transportation System
PCMS	Portable Changeable Message Sign
WZITS	Work Zone Intelligent Transportation System

Executive Summary

Traffic congestion related to road construction is estimated to be more than one quarter of all congestion, a true waste of tens of millions of gallons of fuel each year. While the waste is appalling, the full story is one of the brightest spots in our efforts to conserve. The bright side is that the new technology for 'smart work-zones' is drastically reducing congestion and, in some cases, actually reducing the cost of the construction itself. Strategies such as automated queue warning, delay and alternate route advisory, and traffic performance based work schedules have proven themselves in select states. With continued advances these smart work-zones promise to become the standard for the industry.

iCone® Products LLC (iPL) has been a catalyst in the propagation of smart work-zone technology with NYSERDA backed products such as iCone® and iCount™. These tools have moved the technology from the hands of specialist to the inventory of general contractors. The change has cut costs dramatically. Through the experience of the last several years, iPL has recognized that more can be done to accelerate the adoption of smart work-zones. A primary impediment to this technology is that much of the legacy equipment in states' inventories has not been prepared for the cellular communications and networking that is necessary for a smart work-zone. Equipment hasn't been networked largely because the recurring costs of hundreds, maybe thousands, of cellular accounts for the thousands of message boards and flashing arrow panels is cost prohibitive.

States including California, Texas, and Georgia have asked iPL if it would be possible to adapt the robust networking technology of the iCone® to the networking of other devices, particularly portable message boards. Under Agreement 30527, NYSERDA has provided support to adapt the networking technology of the iCone®, expanding the communication ports and connectors to make it possible to directly connect the device to a portable message board. The resulting product, the NetBox™, allows the networking capability to be carried to those message boards in a state's legacy fleet that need it on particular day updating the fleet with a fraction of the expense of a modem for each device.

By building on the success of the iCone® system, this project introduces the improved networking technology of NetBox™ to the construction industry. Improved networking technology with improved cost structures will accelerate the spread of smart work-zone strategies with the corresponding increase in mobility and reductions in petroleum and emissions.

1 Background

The transportation industry has concluded that increased connectivity, information, and automation is the answer to the need to increase mobility in a time when budgets are necessarily focused on maintaining existing infrastructure. The final configuration of the automation/connectivity solution is something that will certainly be unknown for several more years, but we do know that more information about the activities associate with construction and maintenance needs to be supplied for routing decisions.

The iCone® has changed the world of Intelligent Transportation Systems (ITS) as it relates to highway construction projects, decreasing costs and significantly increasing the utilization of technology. This increase in the use of work zone ITS (WZITS) is creating a demand for the ability to autonomously network other pieces of equipment within the work zone. Information such as the activation of a flashing arrow panel (FAP), changing messages on a portable changeable message sign (PCMS), crash attenuator strikes, and even flagging operations will soon become an integral part of the larger transportation data set.

iCone® Products undertook this project in order to design a generalized device with the capability to autonomously network a variety of roadside construction equipment in a manner similar to the way similar to the iCone® works. This report will summarize the first phase of the effort, a phase in which the electronic controller board is designed, prototyped and tested. Phases in which production equipment is programmed to manage devices such as Dedicated Short Range Communications (DSRC), or Portable Changeable Message Boards (PCMS) will be executed under other contract structures.

2 Design Criteria

From a top level view, the NetBox™ processor design will build on the strong points of the iCone® motherboard design replicating the general philosophy of housing the primary computing and memory capabilities in the primary board and using daughterboards to provide the flexibility to adapt to other tasks.

The general configuration will host the dedicated processor on a mezzanine board, which is common to several products in the board supplier's business. This architecture allows an upgrade path for the processor and economies of scale in production. The processor itself will leverage current mobile device technology. In order to lower costs and speed development the system will operate in a CE and .net environment. This will allow a significant amount of the intellectual property that has been developed for other iPL products to be transferred to the NetBox™ system.

A simple list of functions originally sought follows.

- Low power (neighborhood of <50mA under normal operation)
    - Programmable shutdown to very low power (<5mA)
    - Programmable wakeup from "shutdown" (i.e., periodic "phone home")
- Second/sub-second accurate clock
    - Synchronizable (i.e., to GPS time)
- Wireless communications
    - Cellular - Worldwide
    - Iridium
    - 2.4GHz (i.e., iCount™ radio)
    - 900MHz (i.e., longer range iCount™ radio, or Accelerometer radio)
    - Wi-Fi (maybe)
    - Bluetooth (primarily for sniffing)
- Environmental sensors
    - Accurate GPS
    - Accelerometer
    - Compass (i.e., heading and maybe even inclination)
    - Light sensor (i.e., was the box opened)
    - Temperature
    - Barometric Pressure?
    - Visibility?
    - Road-Surface Temp?

- microSD card, or other easily transferrable memory option
- Local management/debug capability
- LED or other simple, programmable, status indicator
- Extendable / Peripheral device operation
    - Radar (RS-232/Ethernet/?)
    - PCMS (RS-232 and Ethernet)
    - DSRC (Ethernet / RS-232?)
    - Weather Station (?)
    - Camera (Ethernet / PoE)

3 Design Development

The core of the NetBox™ controller is the motherboard which is the center for communications and the management of accessories. Communication systems such as serial ports, Ethernet, Wi-Fi, Bluetooth, and cellular are hosted on the motherboard as well as the overall power management. In contrast with previous controllers used by iCone® products the cellular modem, while still mounted on the motherboard, is detachable and can be interchanged with other modems and other modem technologies. The final result should be an extended service life for the NetBox™ controller.

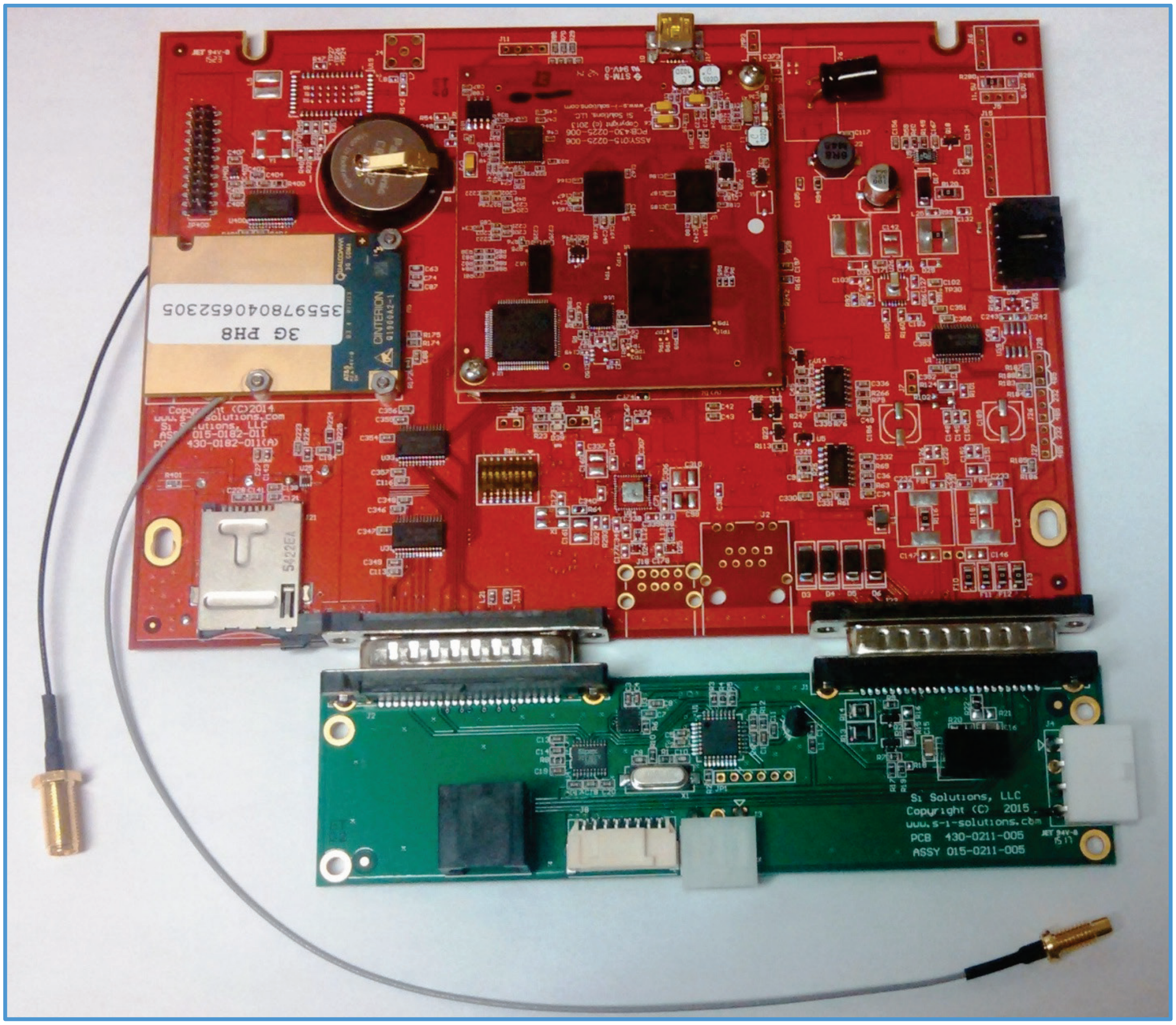
3.1 Hardware Design Development

The specific hardware design of the NetBox™ controller board was performed by the long-time iPL subcontractor SI Solutions.

The specialization of the NetBox™ will come through the design of individual, specialized daughterboards. In order for the NetBox™ to operate a PCMS through an Ethernet connection, a specialized daughterboard will be added, and a different daughterboard will be used to operate an FAP with a serial connection. These daughterboards are relatively in-expensive to design and build, adding less than $100 to the cost of each NetBox™.

The architecture allows us to established three reduced power conditions; Sleep 8-31 Ma, which is the state of the processor between actual processing tasks; Stop 0.3-15 Ma, which is the state of the processor which holds the system between major scheduled tasks such as a communication cycle or radar cycle; and standby 1-19 Ua, which is the state of the processor in storage allowing it to reawaken on a monthly or annual basis to communicate its health and position. The lower overall processor power demand and the addition of the array of low power states will allow the NetBox™ to operate in many modes for months at a time on a battery similar to the iCone® battery. Operating in the iCone® mode it will certainly raise the battery life to well over a month in the field.

Figure 1. NetBox™ controller circuit board with daughterboard



3.2 Software Design Development

The operating software of the NetBox™ controller borrows much from the lessons learned in operating iCones® in the construction industry over the past six years. A particular emphasis is placed on power management and environmental monitoring to allow for the diagnosis of deployment issues and mishandling. The multi-mode communications capability is used to provide both robustness and a certain system diagnosis capability.

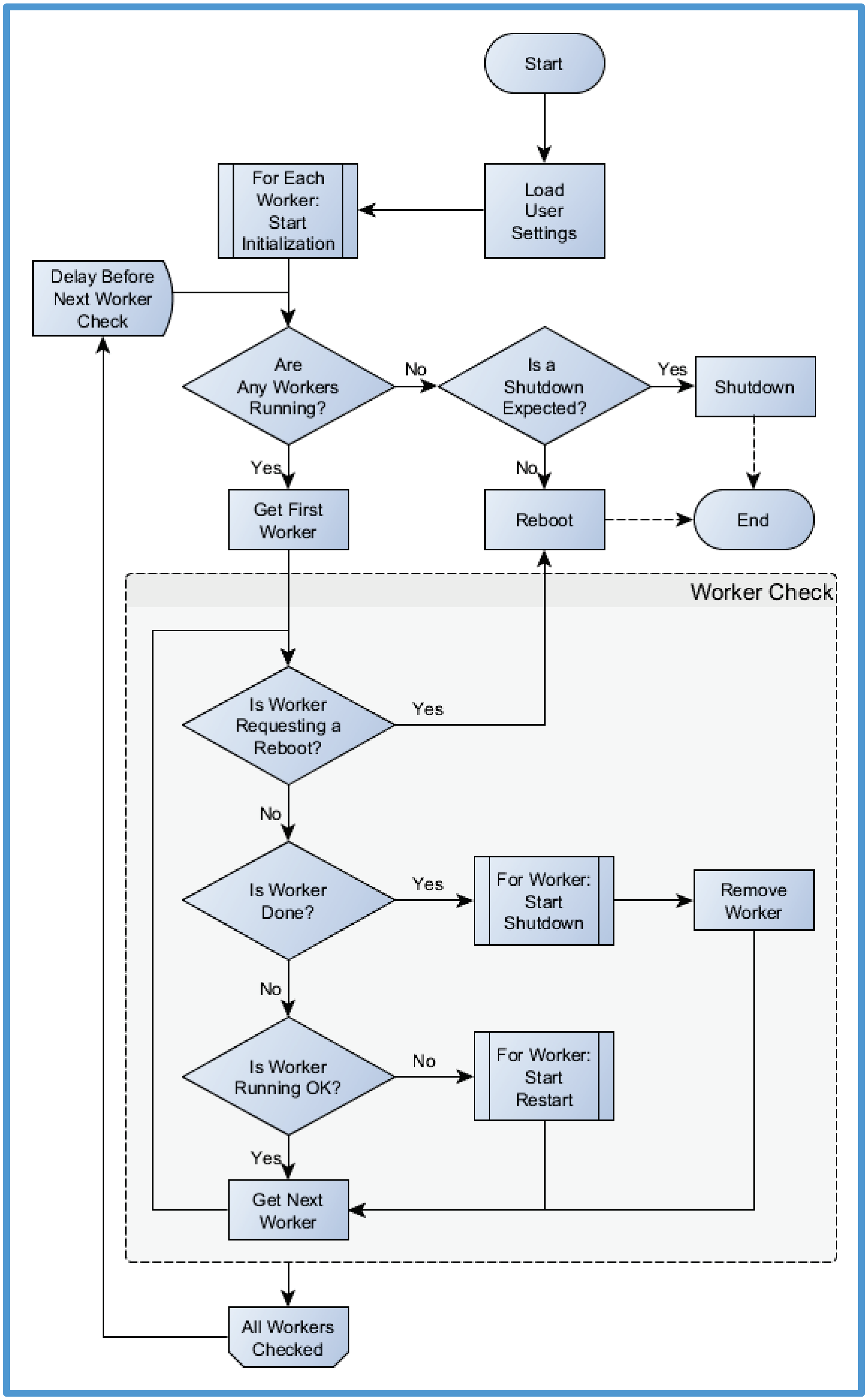
The NetBox™ software is structured to allow easy additions of new hardware features as well as being largely self-testing and correcting. To accomplish this, there's a heavy reliance on a hierarchical structure where every operation is a "Worker." There's a main thread that monitors and manages all workers. Then, there's a "Base" worker that provides all common features of every worker (and is the only object that the main thread can act upon). Finally, each worker defines the processes it needs to accomplish its intended features. Included in these worker specific definitions are optional implementations of self-testing that go beyond whether or not the thread/process is running. If we need to integrate a new piece of hardware at a later date, only the underlying device I/O and these specific worker processes need to be implemented, allowing the rest of the software to remain largely untouched.

The flowchart shown in Figure 2 is intended only to provide a brief, top-level view of the NetBox™ functionality. Flowcharts are generally limited in their very nature to defining linear processes, so there are a number of details that are left unspecified. These include, but are not limited to, all physical device functionality and logic, and most status information descriptions. An attempt has been made to separate between sub-process calls that block the calling process until they are complete and those that run simultaneously (asynchronously). This difference is in two details; first the words "start" and "begin" and second in the symbols used. If a sub-process flowchart is entered using a "Start" within an oval, it is a blocking process, however it is uses a "Begin" in a rectangle with the top corners trimmed, it is a simultaneous process.

- Legend
- Main Loop
- Base Worker
- Worker - Comm
- Worker - GPS
- Worker - Switch
- Worker - Accelerometer
- Worker - Radar
- Worker - Weather
- Worker – Led

The basic operation of the main loop is diagramed in Figure 2. Details of the individual Worker operations are provided in the project's monthly reports.

Figure 2. NetBox™ controller main operational software loop



3.3 Specialized Applications Development

The development of the controller operations software proceeded more smoothly than was originally expected. As a result, the project was able to devote time to developing some of the key specialized software applications that will be needed as the NetBox™ controller is applied to equipment such as PCMS and DSRC trailers.

3.3.1 Device Speed Determination

One of the primary functions of the NetBox™ will be to add iCone® type networking to other highway construction equipment. Included in the list of candidate equipment are a number of truck mounted devices such as truck-mounted-attenuators, or truck mounted speed awareness signs. In these applications it is sometimes necessary for the speed of the vehicle to be factored into the operation of the equipment. Therefore, it is necessary for the NetBox™ to be able to extract the speed of the device from the GPS data.

The GPS module that was designed into the NetBox™ controller board was selected because it offered a number of advanced capabilities. Included in the extras on the GPS module was the determination of the GPS-based speed. As a result, the task of determining the NetBox™ device speed was reduced to developing the code to extract the GPS speed data, developing the additional data storage architecture, and modifying the comm message set to include the device speed data.

Testing of the reliability and accuracy of the NetBox™ device-based speed was executed by loading a NetBox™ in a truck and tracking the location and speed while simultaneously running the SpeedView mobile phone application on the driver's cell phone. Testing was performed over a four-day period.

The NetBox™ was set to generate a device speed every 10 seconds. The SpeedView application automatically updates speed approximately every two seconds. A sample of the resulting data is contained in the charts shown in Figures 4 & 5. Each of the devices had segments where data was not generated for several seconds. These most likely represent times when the GPS constellation was not completely visible. Other than that, the agreement between the two speed records was remarkably high.

Figure 3. Comparison of device speed determination with baseline (1)

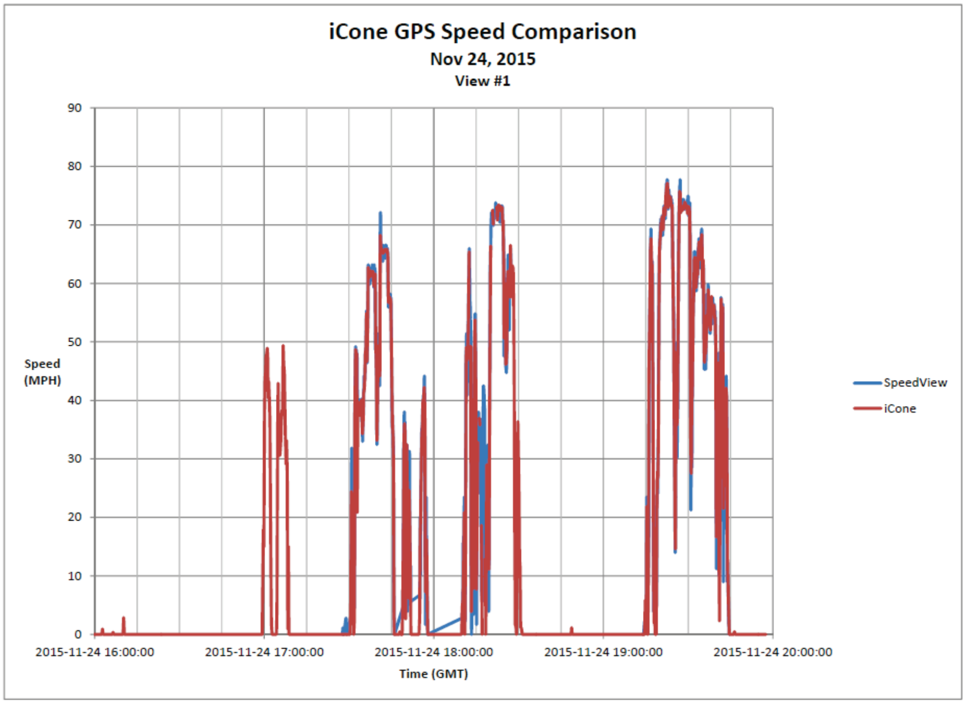
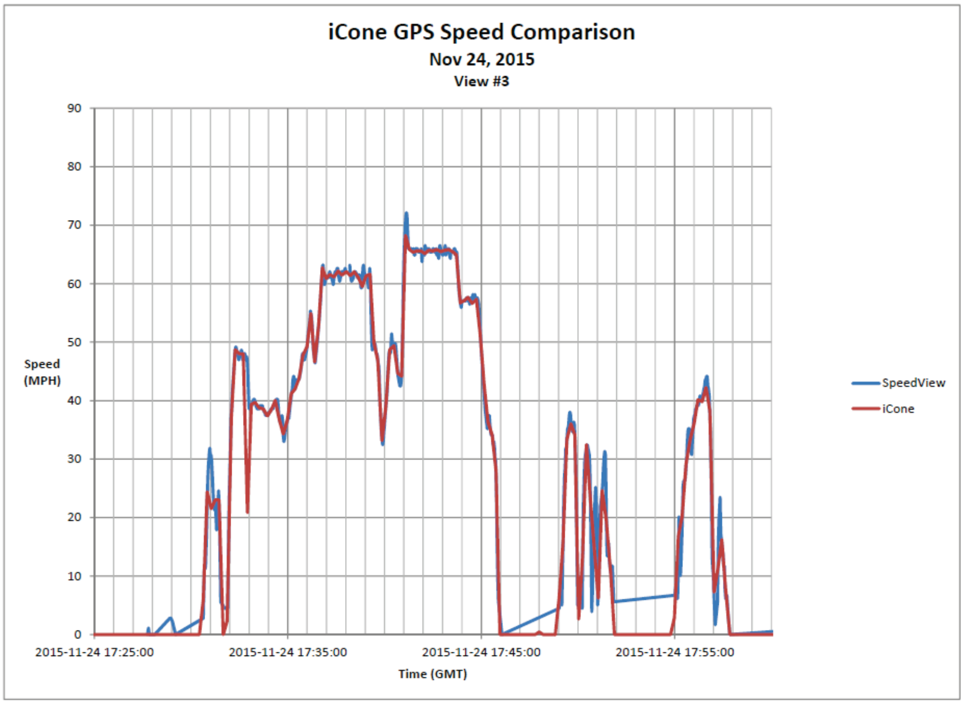


Figure 4. Comparison of device speed determination with baseline (2)



3.3.2 Multi-position Switch Operations

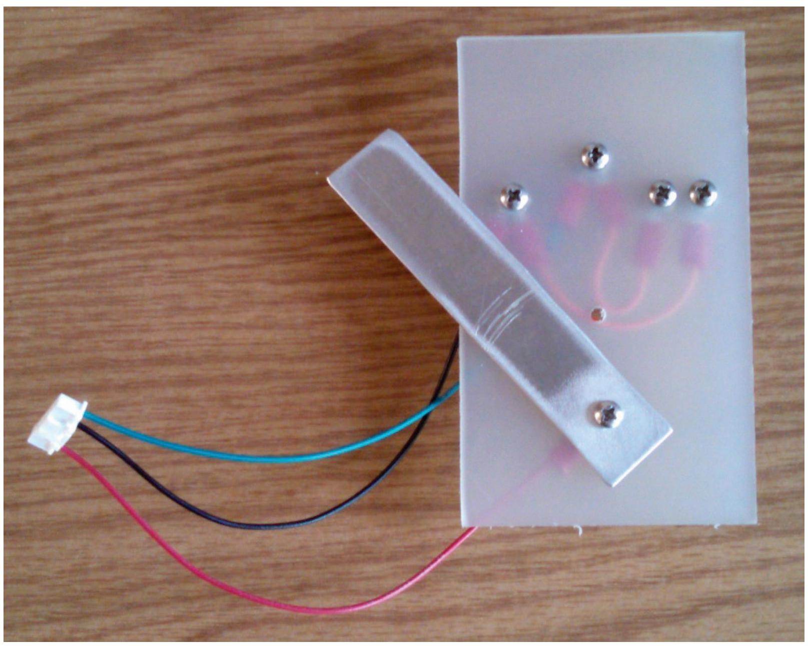
Some applications for the NetBox™ will include the need to recognize multiple states that the attached device has been placed in. For example, an arrow panel may be on flashing right or flashing left. Or a truck mounted crash attenuator may be deployed and may (or may not) be impacted. So, in addition to the ON/OFF switch on the NetBox™ this task created the option for an additional four states through the power system of the 8-pin connector.

The logic is straight forward. There is a power supply line at five volts and a couple of milli-amperes. There are two I/O sensing lines, A and B. This gives four possible states:

- A – 0 volts, B – 0 volts
- A – 5 volts, B – 0 volts
- A – 5 volts, B – 5 volts
- A – 0 volts, B – 5 volts

The proof of concept testing was executed on a simple switch built in the iCone® Products lab.

Figure 5. Multi-position switch test



There is the potential to expand the number of switched combinations through an additional connector on the NetBox™ P11 controller if a use is found for these additional states.

3.3.3 Accelerometer Data Management

The onboard accelerometer of the NetBox™ P11 controller is much improved over the accelerometer of the original iCone® and can give a high degree of detail when used to monitor the activity of items such as crash attenuators or vehicle barriers. In our limited crash attenuator work we have found that practitioners want to have a sense of how hard the attenuator was hit. At the conclusion of this project, there has been no field implementations of the NetBox™ based StrikeAlert. As such, we have not gathered input on how the details of accelerometer data might be used in assessing attenuator impacts. However, we expect that this will be represented in the time history of acceleration amplitudes and recording this high resolution log of accelerations without overwhelming the device memory is what the NetBox™ controller needs to do.

The embedded software for generating a rolling log of accelerometer data has been written and tested. While the logging rate is variable, default settings for this software log the accelerometer reading a 500 millisecond (0.5 second) intervals, but this can be lowered to as fine as 50 milliseconds (0.05 second). As the buffer gets filled old data is replaced by new data. This keeps the total memory commitment for accelerometer data below 100 Mb.

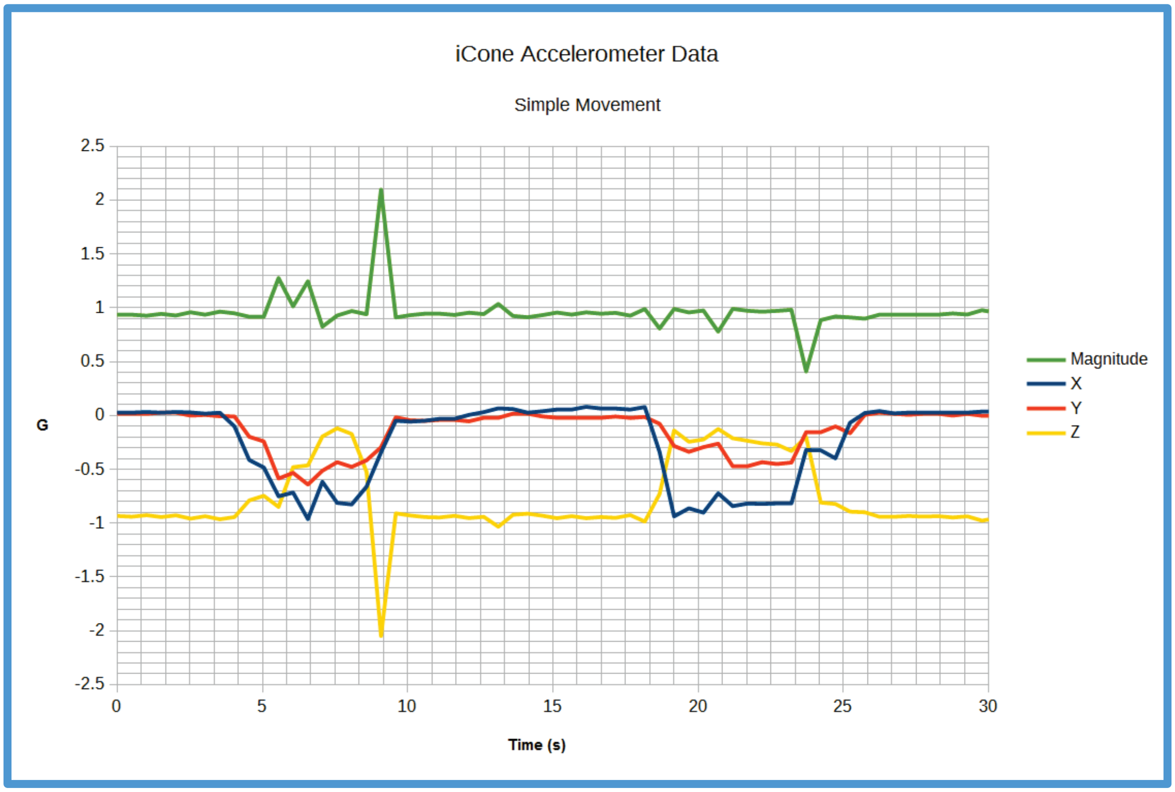
With the expanded memory capabilities of the NetBox™ controller it is possible to compile very large amounts of acceleration and other operational data. At this point it is not conceivable to the iCone® team that there will be a scenario where more than a few hours of data will be needed in a remote download, therefore, the accelerometer data retrieval is set to be separated from the overall internal record to a smaller file that includes the 10 minutes before and the 10 minutes after the event time that is specified in the data request. This decreases the communicated file size to well below a megabyte, appropriate for cellular communications. At this time, the retrieval of these typs of file is not included in satellite communications protocols.

The data is transmitted as a binary file that translates into a text based comma separated file. A sample of the data follows:

- Seconds,SysTick,TimeUTC,Magnitude,X,Y,Z
- 0,7123749,2015-12-29 17:24:32,0.9335765,0.026,0.02,-0.933
- 0.507,7124256,2015-12-29 17:24:32,0.9406088,0.028,0.019,-0.94
- 1.009,7124758,2015-12-29 17:24:33,0.9267907,0.032,0.021,-0.926
- 1.516,7125265,2015-12-29 17:24:33,0.9437166,0.026,0.026,-0.943
- 2.018,7125767,2015-12-29 17:24:34,0.928888,0.032,0.025,-0.928

A graphical example of the accelerator data file is given in Figure 6

Figure 6. Simple handling accelerations display

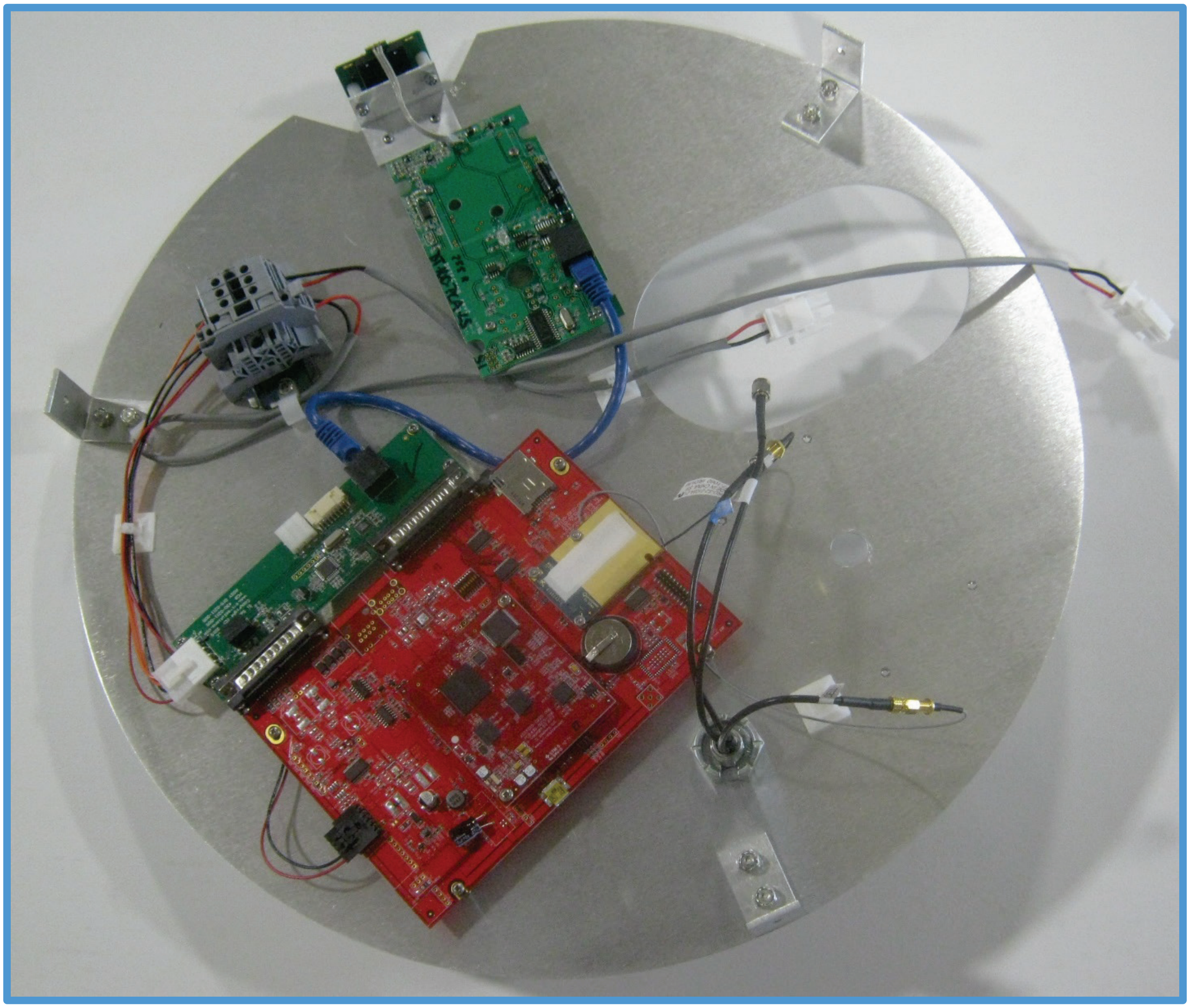


3.4 Prototype Applications – iCone®

The first application of the NetBox™ P11 controller board is in iCones® that were used for the PanAm games in Toronto in 2015. A number of issues, primarily related to processor timing, arose in the first days of the deployment. It appears that the newer, faster processors made the precise timing of the shutdown of various processes difficult. As a result, the system was getting hung on shutdown about 30 percent of the time. During the PanAm Games a series of fixes were put in place to keep the iCones® serving their purpose. By the time the games were completed the significant issues had all been addressed and it was decided that the NetBox™ P11 controller board was functioning adequately to be applied to iCones®.

Since the summer of 2015, the NetBox™ P11 controller board has been used in newly manufactured iCones®. Other production level applications await further funding of the engineering applications.

Figure 7. Application of the NetBox™ controller to the iCone®



3.4.1 Prototype Applications – NetBox™

As the project came to a close the team built up the first P11 controllers into the NetBox™ configuration. The basic function of the P11 as a networking device had been established in bench testing and through application in the iCone® but building it out in a generalized configuration that can be connected to a number of different highway monitoring products was a step that needed to be accomplished.

For the basic packaging, a commercial NEMA 4 enclosure was selected, specifically a Carlon NS12126 polycarbonate box. The P11 circuit board and accompanying daughterboard could potentially fit into a smaller box, but with antennas for both the GPRS/GPS and the Iridium functions the required box size grew to 12x12x6. The requirement for a larger box size did result in the ability to house other components such as secondary modems (DSRC, Wi-Fi, etc.), sensors, or switches in the same box.

A sheet metal fabrication company from Hannibal, New York was hired to fabricate a mounting frame that provides for the mounting of the two antennas, the mother and daughterboards of the P11 controller, as well as secondary devices on a plate elevated above the controller. Candidate internal device include Bluetooth antennas, DSRC radios, Wi-Fi radios, radars, etc. The requisite hardware is shown in the Figures 8-10.

Figure 8. P11 controller chassis for NetBox

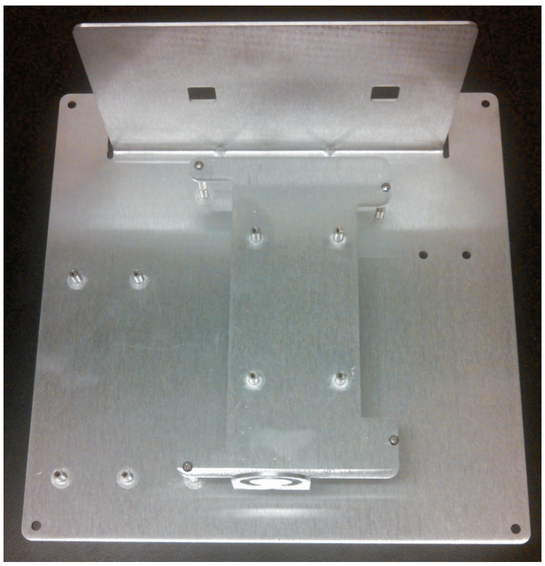


Figure 9. P11 controller mother/daughterboards installed on plate, in box

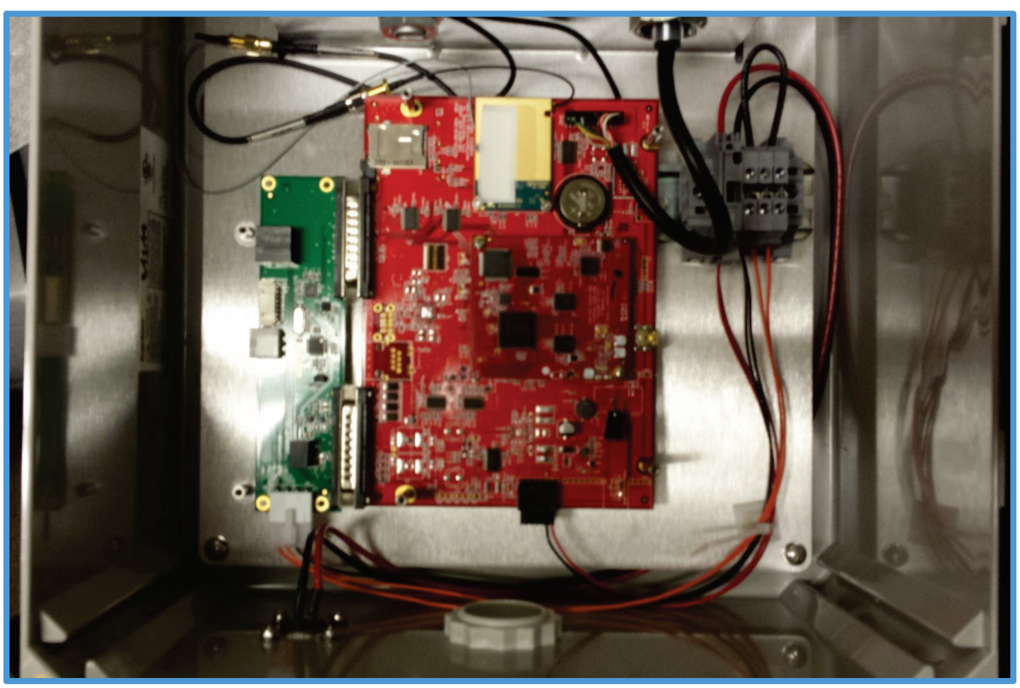
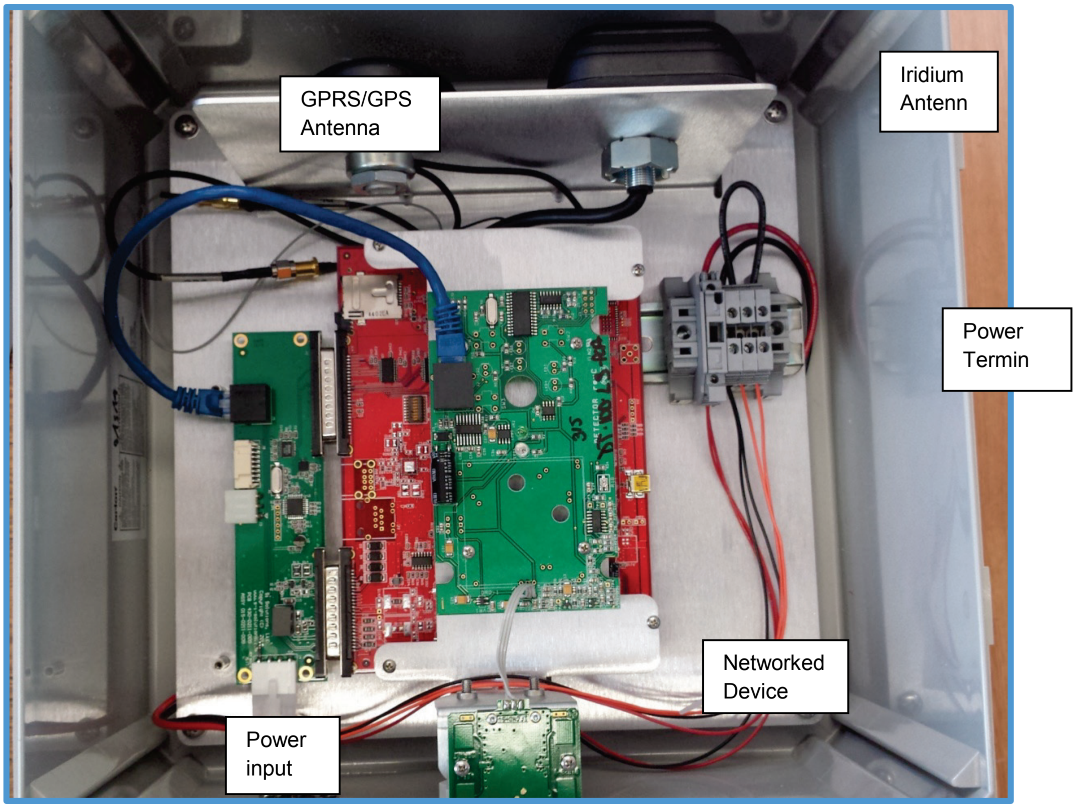


Figure 10. P11 Controller installed with networked sensor elevated



The power feed to the box is through a three pin MIL SPEC connector assuming 12 VDC power supply, the same as most highway equipment (arrow panels, message boards, etc.).

While this first NetBox™ installation is not built for external devices, provisions have been made to include a 5-pin MIL SPEC connector to the box to allow for communications to devices external to the NEMA 4 box. One such application that is anticipated in the near future is the break-away sensor intended to monitor the vehicle-arresting-barriers used on the Long Island Expressway.

4 Testing

The lab testing of the basic functions of the NetBox™ proceeded throughout the execution of the project. As a capability was added sufficient bench testing was performed to confirm that the functionality performed as desired. The steps beyond the bench test are field trials and then broadening field applications with statistical analysis.

This project was intended to design, prototype, and test a controller board which provided similar networking capability of the iCone® controller with broader potential to couple to other devices such as message boards and DSRC radios. Therefore, the primary point of testing for this limited scope is to test the function of the controller as a network device in the environment of the highway work zone.

With successful field testing in Toronto completed the iPL team has deployed more than 100 iCones® into the highway environment. These NetBox™ P11 based controllers have been carefully watched and managed over the past 12 months.

Over this period of extended field applications, a total of 166 units have been operated in the work zone environment. These units have successfully operated for a combined 541,000 hours sending more than eleven million messages. While each specific deployment is unique, iPL spends a lot of time monitoring the function of the iCones® and the other equipment on a job. Many of these deployments are accompanied by an 'After Action Report' which assesses the function of the equipment and the log of traffic conditions during the job. A sample 'After Action Report' from a one-night job in Texas is provided in Appendix A.

Like any functioning system, these operations have not been without failures. Through the more than half million operating hours the NetBox™ P11 controller has logged 170,638 system 'boot up cycles'. Of these boot cycles, 302 are known as explicit, automatic re-boots that the controller has performed on itself to clear an error. While we are not certain of the number of times that the system was manually re-booted by a human operator to clear an error that it didn't automatically clear, it is highly probable that the number of errors that required manual re-booting is a fraction of the times in which the system corrected itself through an automatic re-boot. This would seem to indicate that somewhat less than 150 manual re-boots have been necessary on 166 units over the last year. It seems safe to deduce that approximately one manual re-boot operation is needed for every 12-24 months of operation.

The project has clearly resulted in a networking system that can function with relatively little maintenance in the highway work zone environment. Whether or not the current level of reliability meets the reasonable demands of a field system will always be an issue to be debated and addressed. From a purely anecdotal point of view the iPL team seems to spend significantly more time addressing issues with other equipment, such as message boards, than is spent with NetBox™ P11 controller boards.

5 Summary

At the time of the writing of this report the climate in the world of work zone technology is rapidly shifting. Concepts such as Connected Workers, Connected Flagging, and Connected Work Zones are being discussed at nearly all meetings of transportation professionals. The specific ‘connection’ technologies are still strongly debated and it may be that DSRC falls into the background. What is clear is that advances in connected and automated vehicle technologies will require detailed knowledge of the road ahead in order to confidently pass from A to B. The work zone remains the single largest anomaly in the mapped highway network. Interest in making that state of equipment such as flashing arrow panels, programmable message boards, and crash attenuators is growing rapidly.

The NetBox™ controller has been successfully in use in the iCone® for more than a year with very positive results. Further development of the NetBox™ itself for applications such as attenuator monitors or truck mounted attenuator monitors are expected to begin in late 2016 or early 2017. The realization of the broader networking potential of a technology such as the NetBox™ will take time and financing. In the meantime, the technical capability has been established and experience with the basic functions is growing by the day.

Appendix A

After Action Report

Date: June 24, 2016

Deployments Being Reported: 1

ID	Project	Plan	Direction	Reporting Time Zone
4800	3A-2	2	NB	Central

Observations
Stopped traffic conditions at the taper (iCone #1), queueing and stop and go possible.
Stopped traffic conditions at iCone #2, queueing and stop and go possible.
Stopped traffic conditions at iCone #3, queueing and stop and go possible.
iCone #4 did not reported.
Stopped traffic conditions at iCone #5, queueing and stop and go possible.
Stopped traffic conditions at iCone #6.
Slow traffic conditions at iCone #7.
Slow traffic conditions at iCone #8.

Sample 'After Action Report' detailing the operation of equipment and traffic characteristics during the project. This particular project was a one-night lane closure on I-35 with an eight iCone® queue warning system installed.

The Observations table summarizes the performance of the equipment and the traffic events of note at each location.

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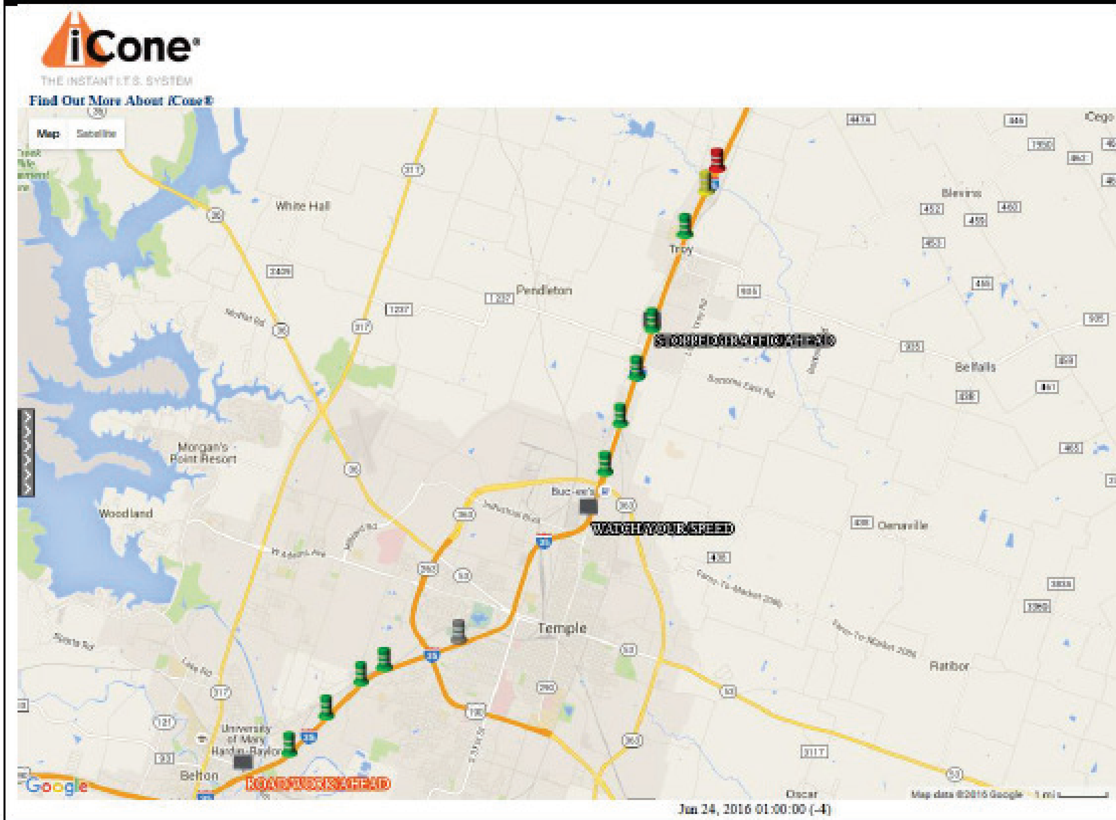
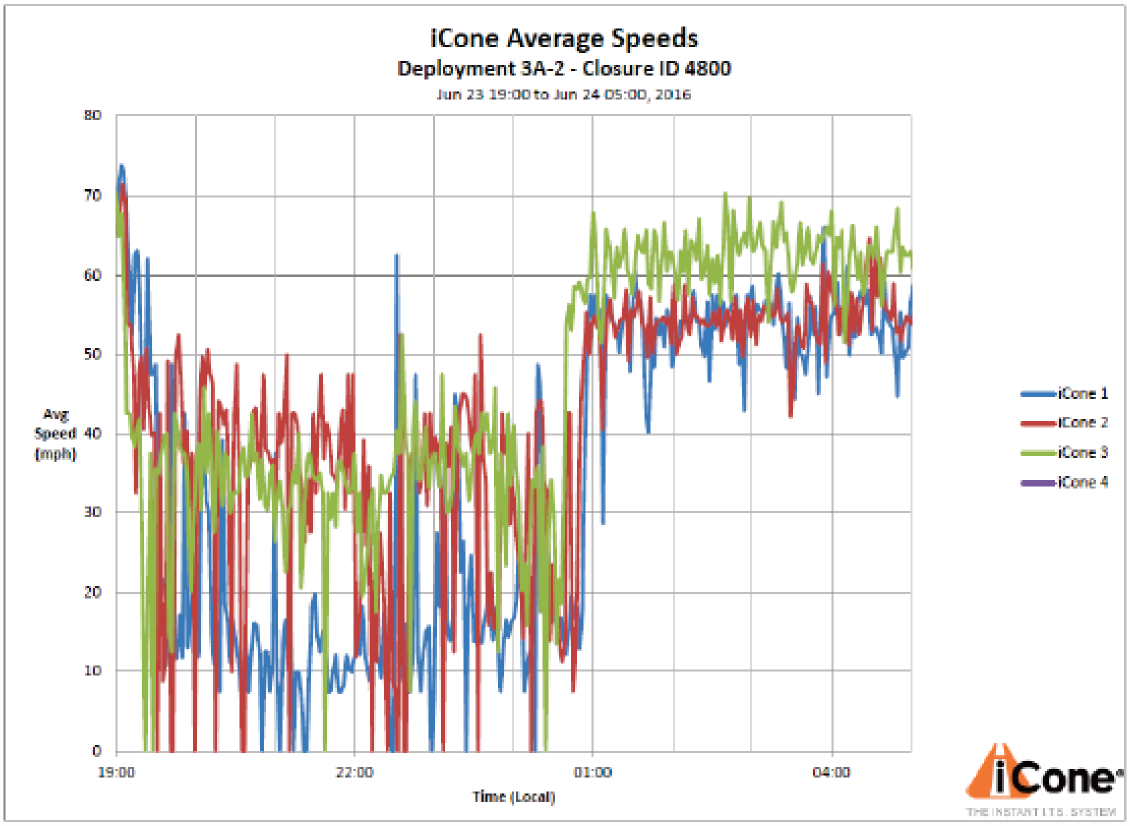
Map



The 'After Action Report' includes a screen capture of the iConeTraffic.com website showing the system in operation on the project.

The section of I-35 north of Temple, Texas is the project that is the subject of the report. The project is northbound with seven iCones® displayed (one did not function) and two message boards.

Average Speed Chart (iCones 1 to 4

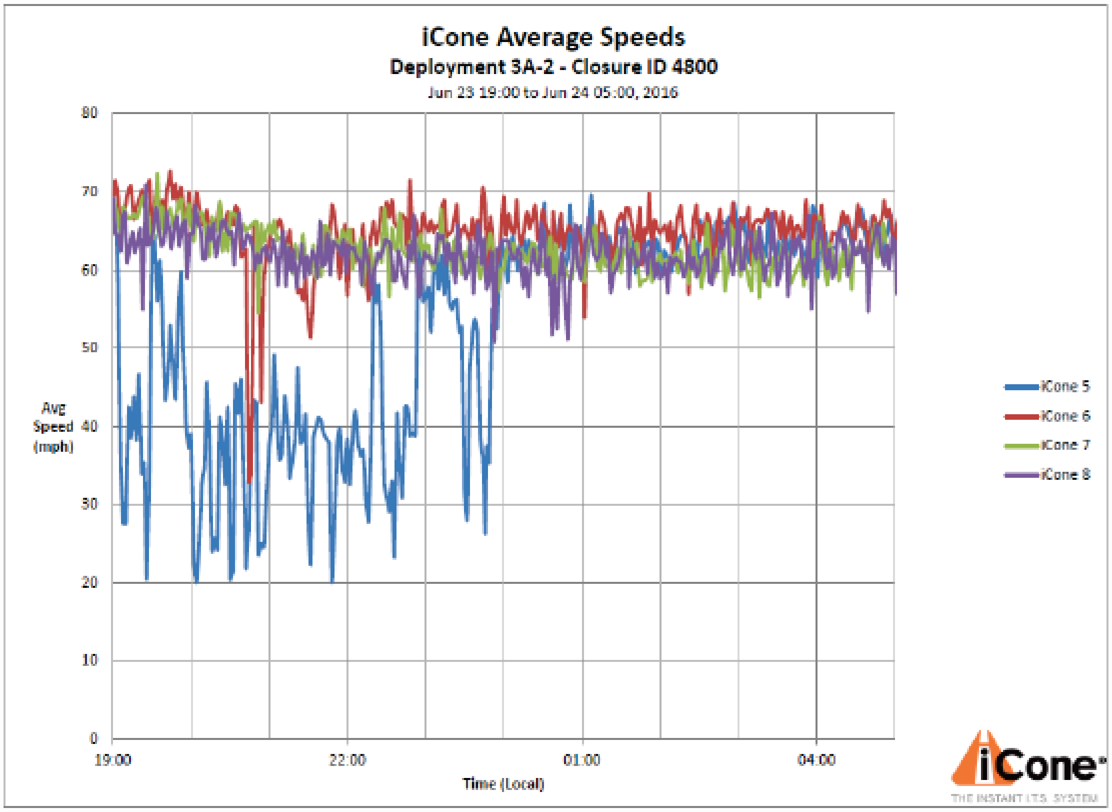


The 'After Action Report' includes charts of the time history of each iCone® during the period of the report.

iCones® are numbered from the point of the lane closure (iCone® 1) upstream (iCone® 8).

The chart shows significant slowing, 'queuing' through the first three iCones® until 1:00 a.m.

Average Speed Chart (iCones 5 to 8)



iCones® 5 through 8 are shown on a separate chart.

The chart shows significant slowing, at iCone® 5 (3.5 miles upstream) until midnight.

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New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov