IDEA

**Innovations Deserving
Exploratory Analysis Programs**

Transit IDEA Program

Light Rail Transit / Street Grade Crossing Safety System

Final Report for Transit IDEA Project 68

Prepared by:
Carl E. Conti, SIL4 Systems, Inc.

January, 2014

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Innovations Deserving Exploratory Analysis (IDEA) Programs Managed by the Transportation Research Board

This IDEA project was funded by the Transit IDEA Program.

The TRB currently manages the following three IDEA programs:

- The NCHRP IDEA Program, which focuses on advances in the design, construction, and maintenance of highway systems, is funded by American Association of State Highway and Transportation Officials (AASHTO) as part of the National Cooperative Highway Research Program (NCHRP).

- The Safety IDEA Program currently focuses on innovative approaches for improving railroad safety or performance. The program is currently funded by the Federal Railroad Administration (FRA). The program was previously jointly funded by the Federal Motor Carrier Safety Administration (FMCSA) and the FRA.

- The Transit IDEA Program, which supports development and testing of innovative concepts and methods for advancing transit practice, is funded by the Federal Transit Administration (FTA) as part of the Transit Cooperative Research Program (TCRP).

Management of the three IDEA programs is coordinated to promote the development and testing of innovative concepts, methods, and technologies.

For information on the IDEA programs, check the IDEA website (www.trb.org/idea). For questions, contact the IDEA programs office by telephone at (202) 334-3310.

IDEA Programs Transportation
Research Board 500 Fifth Street,
NW Washington, DC 20001

Light Rail Transit / Street Grade Crossing Safety System

Final Report

Transit IDEA Project 68

Prepared for

Transit IDEA Program

Transportation Research Board

National Research Council

Prepared by

Carl E. Conti

SIL4 Systems, Inc.

Pittsburgh, PA

January 2014

ACKNOWLEDGEMENTS

This panel reviewed the previous Stage Reports and their input has been included in this report. This document is the Final Report documenting the results of this project. It includes the results of all stages of this project. This report is being sent to the Panel for review and comment/feedback. We held a teleconference with the Expert Panel and the feedback/recommendations gleaned from this teleconference as well as electronic commentary are incorporated in this Final Report in the pertinent sections.

TABLE OF CONTENTS

SECTION 0: Executive Summary

SIL4 Systems Inc. was engaged in a Transit IDEA project 68 to develop and test an intelligent Light Rail Transit / Street Grade Safety System that can be used by Light Rail Transit Systems.

The concept investigated and being developed in this project is active, adaptive, alert, and improves recording of crossing incidents for the approaching Light Rail Vehicle (LRV) its operator and the pedestrian, motorist, and/or worker at the crossing. An outline of the system features and impacts are listed here:

FEATURE	IMPACT
+ Active System – Alerts Operator	Improved alertness/response time of operator
+ Active System – Alerts Trespasser/worker	Improved alertness/response t of person at risk
+ Improved alertness/response time	Actively alerts operator and pedestrian/motorist
+ Active System – Applies Brakes	Actively alerts operator then applies brakes
+ Adaptive – works only when train approaches	Avoids false triggers
+ Comprehensive Record	Records events on the train and in the crossing.
+ Adaptable / Portable	Can be set-up in temporary work areas.

This is the Final Report documenting the results of this project. It includes the results of all stages of this project.

The project has been performed in three contingent stages. Stage 1 was the survey and analysis of the solutions features and components and was completed in December 2012.   Stage 2 focused on the system development, component procurement, development and refinement and was completed in April of 2013. Stage 3 has been focused on final packaging and component and system testing, and then ultimately a field test; a draft final report and the final report in Stage 3.

SECTION 1: Stage 1 Results

An electronic Survey was prepared and has been sent to key decision makers are various rail authorities throughout the country. SIL4 Systems joined APTA in order to obtain a listing of key/pertinent people in each of the organizations/transit authorities and to begin to cultivate the relationships with those interested in safety. Specifically, we focused on ones that were listed in the

They included the following authorities:

1.	Atlanta, GA	MARTA	15.	New York, NY	NYCTA
2.	Baltimore, MD	MTA	16.	Newark, NJ	NJ Transit
3.	Boston, MA	MBTA	17.	Philadelphia, PA	SEPTA
4.	Buffalo, NY	NFTA	18.	Pittsburgh, PA	PAAC
5.	Chicago, IL	CTA	19.	Portland, OR	Tri-Met
6.	Cleveland, OH	GCRTA	20.	Sacramento, CA	RTD
7.	Dallas, TX	DART	21.	Salt Lake City, UT	UTA
8.	Denver, CO	RTD	22.	San Diego, CA	SDTI
9.	Hudson-Bergen	NJ Transit	23.	San Francisco, CA	MUNI
10.	Houston, TX	METRO	24.	San Jose, CA	Santa Clara VTA
11.	Los Angeles, CA	LACMTA	25.	Seattle, WA	ST
12.	Memphis, TN	MATA	26.	St. Louis	Bi-State
13.	Miami-Dade, FL	MDT	27.	Washington, D.C.	WMATA
14.	New Orleans, LA	RTA			

1.1   Survey

Responses to the survey came in and we analyzed the information in order to assess our solution feature set to help assure it will have features perceived by various authorities needed to enhance crossing safety.

We will also did in-depth interviews with those that conceded to co-operate and provide more detailed feedback and commentary on Highway Rail hazards and associated mitigation strategies. The top responders were asked to join the Review Panel. Keep in mind that for this survey, we had to put together a light enough survey to elicit some response versus being ignored and at the same time try to extract some high level feedback on their situation and their assessment of the perceived problem and perceived solution. This is a task that takes time to cultivate so we did continue this throughout this 10+ month program, primarily with the Review Panel.

The Survey detail questions are covered here one at a time with our analysis to follow. The first 3 questions attempted to characterize the Authority as to the number of Crossings, Type of Signage and the number of incidents:

1) How many Highway – Rail Crossings does your Transit Authority operate:

   a) 25 or less   ~40% of respondents
   b) 25 – 50   ~40% of respondents
   c) 50 -100   ~10% of respondents
   d) 100 +   ~10% of respondents

2) How many Highway – Rail Crossings incidents (pedestrian or Motorist) do you have per year on average:

   a) 10 or less   ~70% of respondents
   b) 10 – 25   ~15% of respondents
   c) 25 – 50   (1 per week)   ~15% of respondents
   d) 50 +   0% of respondents

3) What type of Highway – Rail Crossings Signaling/Signage do you currently have at most Crossings:

   a) Passive Signage (Cross-Bucks)   ~15% of respondents
   b) Flashing Red Lights   ~15% of respondents
   c) Lights and Gating   ~55% of respondents
   d) Other _____   ~15% of respondents

The Transit Authorities targeted in our Survey were the ones that were cited in the proposal reference study and ones that we think would be most in need/sensitive to Highway Crossing Safety. Most all of the Authorities that responded have 50 or less crossings. We will reach out to the Authorities that have the most crossings such as: Island Transit (Galveston); Portland Tri-Met; New Orleans; Los Angeles (LACMTA) and Sacramento (RTD) and in an attempt to schedule further trials for the system.

So far as incident frequency, most had '10 or less' or 'one per month' at most. However a few had frequencies of 1/week.

Most had combined lights and gating systems. We did follow up with them and noted that our system will complement their system while not interfering in any way. They did seem to appreciate that feature and that the perception of the incident being video / monitored would perhaps change behavior at the intersection and while video camera are becoming ubiquitous and perhaps intrusive in some cases, in this case there is no "Intrusion" factor and that it is only to enhance awareness and safety and respondents concurred on this point.

A few of the people wanted to know the exact system we were proposing in order to discuss it and now that we have the base car-borne package and key Crossing components defined we can put together a concise Product/System package for them to evaluate and provide feedback. This was a key task in Stage 2 - to develop a key Product Feature Set for a Highway Crossing Safety Solution and have them evaluate it, not a TRB concept but a more detailed/defined system with exact performance perimeters and component features.

In question 4 we asked whether the person would be interested in providing more detailed feedback on Highway Rail Safety.

4)   Would you be interested in providing valued feedback on a Highway – Rail Crossings Safety Enhancement System?

a)   Yes   ~75% of respondents
b)   No   ~25% of respondents

75% agreed to do provide additional information. The next 3 questions attempted to get their information on the likely causes of incidents and the features for safety improvement.

5)   If YES, please continue:

Please rate from **1 to 6** each of the following as likely causes of incidents (1 = Most likely;   6 = Least likely):

1 – 33%   2 – 25%   Pedestrian/Motorist risky/ill-advised behavior

2 – 33%   3 – 10%   Pedestrian/Motorist confusion

2,4,5 – 10%   3 – 25%   Inadequate / confusing signals or queuing system?

3,4, 5 – 10%   3 – 25%   Inadequate Public Awareness

3,6 – 10%   4, 5 – 25%   Inadequate late-stage warning.

1, 2,   6 – 10%   Other _____

Many of the Respondents, some 70%+ of them, felt that the Pedestrian/Motorist behavior was the highest cause for incidents. 60% selected "Pedestrian/Motorist risky/ill-advised behavior" was in the top 2 (highest) likelihood of cause. It has been our approach all along that this was the case as it was the key component of our system feature/impact which was to increase the ALERTNESS of the pedestrian / motorist but ONLY during an approaching train scenario so that they not have false sense of safety when crossing warnings are lit but no train arrives, they then begin, as is human nature to "game" the system attempt to race the approaching train and it only takes one or two successes before they may think this to be a low risk move, and while this is ill-advise behavior it is human nature.

A few respondents chose "other". Descriptions that we received on these were express essentially as "Left turns (motorists) on parallel movements in same direction on street running alignment" and "Lack of consistent enforcement".

We needed to drill into the exact scenario of the LEFT TURN as it was clear from research and anecdotal evidence that this is a common scenario and, it should be noted that "lack of consistent enforcement" can have adverse effects on sustaining any pedestrian/motorist modified behavior.

Next we tried to glean some impressions on what feature/impact could improve safety at highway crossings.

6)   Please rate from **1 to 6** each of the following Highway Rail Crossing Features that would likely IMPROVE Safety (1 = Most likely to improve Safety;   6 = Least likely):

 1 – 25%   2 – 33%   Increase Pedestrian/Motorist awareness

 1, 3, 4 – 10%   2 – 25%   Lessen Pedestrian/Motorist confusion at Crossings

 2 – 33%   3, 5 – 10%   Clearer signals or queuing system

 1 – 10%   2, 3 – 25%   Increase Public Awareness of Crossing Dangers and Safe-guards

 4 – 33%   2, 3 – 25%   Increase late-stage warning.

 1 – 25%   2 – 10%   Other _____

70%+ of them, felt that increasing Pedestrian/Motorist awareness and decreasing confusion would yield the highest results in terms of improved safety. The responses here eliciting comments on solutions, somewhat mirrored the causes question but yielded also some interesting insights.

Again it has been our approach all along that this was the case as it was the key component of our system feature/impact which was to increase the ALERTNESS of the pedestrian / motorist. When one looks at decreasing confusion, it would seem, at least for pedestrian case that managing their ingress to, and egress from, the crossing can be a key component. This also acts to alert/direct them to the signage that may be missed if they enter it from varying angles and entry/exit points.

We also draw upon human nature by featuring a camera system in the crossing. In our discussions with some respondents, it became apparent that this camera presence should be very conspicuous and in fact a sign showing that a camera is present and recording would be very effective.   Here are 3 options that we will be looking at in Stage 2 and assessing their communicative impact and effectiveness.

FIGURE 1.1: Three possible Camera Alertness Signs

We will likely construct a hybrid sign that will take the best features of each of these and combine them. The panel recommended we search MUTCD Docs for guidance. The *MUTCD 2004 Standard Highway Signs – 2012 Supplement* edition was perused for guidance on Camera/Warning signage. There was not a specific listing for security cameras however it is clear that all warning signs have yellow or red in them. The closest relevant sign

we found was "photo enforced" sign that was black with yellow background. Also we need to include the word "Crossing" in the warning to assure they know exactly what it is that is being monitored. We would also need to include the work "Recorded" as well to alert the person that it is just, that, recorded and not just "monitored." Icons over words, are most effective.

8)   If you chose "other", please describe:

   A few of the more interesting responses the "Other" queries were:

   "Use of 4 quadrant gates at selected crossings"   We will look at these devices and analyze what type of crossings characteristics these would be most effective within. We will also look as what it is that we may be able to incorporate in this program. We will report on and update this aspect after Stage 2 and in the Final Report.

   "Delineators along the alignment and pavement etchings to warn motorists of abnormal condition" Again, we will look at these devices and analyze what type of crossings characteristics these would be most effective within. We will also look as what it is that we may be able to incorporate in this program.   We will report on and update this aspect after Stage 2 and in the Final Report. It should be noted that the features we tried to incorporate in our base system are features that would seem to enhance most universally any scenario including remote/mobile application.

   "Stop designing as we always have and create separation" This is an interesting remark/comment and while we   agree this is ideal, it does not acknowledge the inherent difficulty and cost of retro-fit. But the spirit of this remark should not be ignored in that in some scenarios the ONLY way to assure that the motorist and/or pedestrian does not wonder into harms' way either is to physically restrict them from doing so.

   There was also a comment call for more "Active Pedestrian Warning Treatments."   We will address some such system / devices later in this section.

7)   Do you think a conspicuous camera in the Crossing would improve and make more cautious Pedestrian / Motorist behavior?

   _____ Very Likely to improve caution   _____ No change

   _____ Somewhat Likely to improve caution   _____ Cause more risky behavior

   Some interesting feedback came in pertaining to specific causes/scenarios such as *" Left turns (motorists) on parallel movements in same direction on street running alignment".*   We drilled into this scenario a bit more and evaluated the signage/warnings/alerts at these intersection and see if we can address them in some manner.

   We conducted phone interviews with a few folks. One in particular interview, the person stressed "separation" and did so because he said that there are last second scenarios of either the motorist or especially the pedestrian type where no detection/warning/reaction system can hope to prevent.

   To that point - physical separation and/or physical restriction is a key and recurring theme in some of the feedback.   Thus one can conclude 4-quatrant v 2-quadrant gates; and metal versus light-weight plastic material is also recommended.   We also did some internet and *youtube* searches and encountered "Light Strips" built into the roadway across the LIGHT RAIL / STREET CROSSING entrance that illuminate the approach quite well.   Two limitations to this are that snow and ice would interfere and if you are too close you may not see them over the hood of a car and this would be more dramatic for a truck or RV type vehicle.

We also reviewed various scenarios that seemed to be synonymous with LIGHT RAIL / STREET CROSSING incidents in the following section.

1.1.1   LRV and Cars Running Parallel

In this scenario you have one or likely 2 LRV tracks running closely parallel to each other with opposing traffic and you have adjacent surface traffic running in the same direction as the adjacent LRV line. Typically in these applications the speed limits of both the cars and LRVs are the same.

Review of video recordings of accidents involving LRVs and cars reveal that several strategies would be helpful in preventing collisions. One is to provide motorists with better signage and other indicators that an LRV train is approaching and that a left turn would be unsafe (preventing motorists from turning left when the light is green but the LVR is coming from behind them and to the left). Car drivers do not look in side-view mirrors for trains nor are those mirrors set to see something that is effectively 2 or 3 lanes over. With mirrors in mind, however a mirror reflecting the oncoming train while low-tech, if it were sizeable enough would reveal the oncoming train that is running in parallel behind in the blind spot, the approaching car/truck and this may be a fairly inexpensive solution. One would need to be aware of addressing glare and other nuisance aspects of a mirror.

A light clearly stating NO LEFT TURN when the LRV is approaching would be clearer than just a typical traffic light since drivers are not accustomed to looking over the left shoulder before making a left turn. In addition to clearer signs and signals for drivers, a physical barrier such as a four quadrant gate when the train is approaching would prevent drivers from completing the turn in front. Again, four quadrants rather than two would prevent drivers from trying to get around the gate and beat the train.

These gates should be made of sturdy materials such as steel so that cars cannot drive through them.

Example video is referenced here. "Metro's Greatest Hits" YOUTUBE video:

http://www.youtube.com/watch?v=CV2rdGX4JYc

Video 1a: Grey car next to white truck starts turn with Green light ahead.

While this car does turn left, directly in front of the trolley/LRV - there seems to be no signage warning and 2 green lights ahead of them.

Video 1b: Low speed collision seconds later with approaching LRV.

1.1.2   Cars and LRV at Perpendicular Intersections

Otherwise cautious and diligent drivers sometimes run a yellow or even a 'freshly red' light when they are in a rush, running late or when they distracted for any number of reasons (all of which are becoming more prevalent and alluring, not diminishingly so) are not paying attention to their traffic signals. This can be especially dangerous when an LRV train is crossing the intersection in front of the car. A product called a Lighted Stop Bar can help call attention to the fact that the traffic light is red and that a train is approaching (not used when there is a red light and a train is not approaching). This helps motorists to be more alert to the approaching train and less likely to run a red light due to inattention.

Lighted Stop Bar Video:
http://www.youtube.com/watch?v=XK7cvkPZuyM
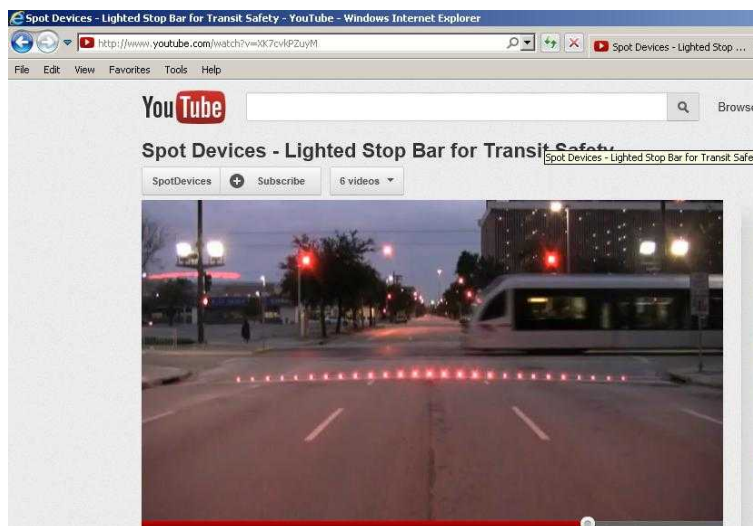
Video 2:   Pavement embedded Light Bars at Light Rail / Street Crossing.

Again, two limitations to this are that snow and ice would interfere and if you are too close you may not see them over the hood of a car and this would be more dramatic for a truck or RV type vehicle.

Another recurring remark that had some weight was that to change behavior you have to have instant or at least very consistent and reliable enforcement.   Otherwise while some feature may deter behavior, if there are no certain consequences to violating it, then after a while, this will be discovered and behavior will slowly revert back to nearly where it was prior.

One such instant enforcement that was suggested could be a physical barrier such as tire spikes that can deter drivers from attempting to cross rail tracks when a train is approaching. Tires spikes have the advantage of being unobtrusive when a train is not in the area, but can prevent severe injury caused by a car being hit by an approaching train. This type of enforcement is likely to be effective because it is immediate negative reinforcement for the driver. If used, spikes should be set back far enough from the tracks that a car would not be rendered unmovable dangerously close to the rails. There are obvious risks and hazards to this approach: mal-functioning; the damage vehicle may either itself be less safe than before and /or create a nuisance/distraction at the intersection that may only raise the level of sporadic, unpredictable and risky behavior so this is seen not a viable option.

All-seeing 24/7 monitor cameras may, along with some other enforcement mechanisms be a viable method of changing behavior.   Key to this would be the enforcement aspect of it and we will be looking at this more as the program progresses.

Traffic Light Alertness enhancement – LED Back-plate Lighting:
Per a panel member - Texas Transportation Institute did a study that showed the embedded light bars made a statistical change in illegal right turns on red whereas the LED back-plates (such as those shown in Photo 1a and 1b below) made a statistical change in preventing red light running. They are used sporadically throughout the Downtown Houston area since, like the embedded light bars, they are both in the experimental stage.

Photo 1a: LED backplate lighting enhancement   **Photo 1b:** LED backplate lighting

This, of course, could be used to enhance alertness in crossing approach signage and lighting and could be a simple relatively cost-efficient way to enhance awareness.   As with any enhancement, one would have to study the long term affects.   Initial results due to a 'newness' of the scene/experience may result in only a temporary change in behavior. Secondly and just as important, if motorists become used to these, might it also have an unintended consequence (inconsistent expectations) in making them less alert at intersections where they are not installed.

1.1.3   Pedestrian Safety

Similar comments were gleaned from the survey on Pedestrian Safety. That yes, cameras with conspicuous notices that they were there and recording 24/7 would be effective in changing risky behavior but that the long-term effectiveness will have to have an enforcement component to it.

Also that more controlled entrance to the crossing would improve safety as well as alertness to warning signage as depicted below (http://www.youtube.com/watch?v=FdB9xXzvsw8):

Video 3a: Controlled pedestrian crossing entrances with warning signage

This same video also shows pedestrian bars/ gating with very conspicuous signage both passive and electronic.

Video 3b: Pedestrian bars/gating with passive and active signage at crossing.

It became clear that the Crossing System needs to be flexible and in some way interact with other equipment / safety aspects such as bars/ gates and active signage in the crossing as well as being tied into an

enforcement aspect.   To that end we will have additional capabilities on our crossing equipment package that include:

- Digital Outputs that can drive relays and energize/activate other equipment
- Wi-Fi for local communication with other equipment including enforcement aspects.
- 3G for local communication with other equipment including enforcement aspects, safety aspects and alert features that may be deployed.

With the varied responses that we've had, it became increasingly clear that we must include a flexible "menu" of features, easily deploying some feature in some applications, while others may be more useful in other applications/scenarios with a mind toward "complementing" the systems that are in place.

An excellent video depicting pedestrian behavior of all ages and with strollers, carts and even motorized carts is captured in this "close-call" video 3C below. It can be viewed at:
http://videos.oregonlive.com/oregonian/2012/05/pedestrian_has_close_call_with.html

Video 3c: Pedestrian behavior at crossing and "close call"

And a pedestrian jumps a fence and just misses by inches of being hit can be viewed at:
http://www.youtube.com/watch?v=N52t5Hq6RiY&oref=http%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3DN52t5Hq6RiY&has_verified=1

Video 3d: Pedestrian jumps fence and is nearly hit.

SECTION 2: Stage 2 Results

Again, Stage 2 focused on system development and refinement, component procurement, software application development and verification testing.

2.1   Pre-Trial Test Plan

SIL4 wrote a Pre-Trial test plan and also conducted specific car-borne package tests; communications tests and HRC component /system tests in order to de-risk the trial installation and subsequent test trial.

2.2   Component Selection

SIL4 investigators performed a final review of the field Trail installation and test in preparation for installation of equipment, pre-test qualification/verification testing and final Trial Test plan.

The pilot design system, including COTS components, will be tested and tweaked for maximum performance. SIL4 investigators will prepare to run a simulated field test will the car-borne package mounted on a motor vehicle to test dynamic performance (range and sensitivity) of the communications system. Other tests deemed pertinent to de-risk the Field Trial also will be run.

Some of the input from Panel members was to warn against over-burdening the operator, for example with yet another monitor to watch. In light of this, we'd propose that the monitor would be in secondary view nand perhaps the video panel would be small and only when a scenarios where the LRV is approaching a crossing and "occupancy" and/or "motion" is detected, would he/she receive a audible alaem in the cab as well as the video going automatically to full screen. The challenge here is of course, trying to avoid false positives/nuisance warnings.   While we are able to do Motion detection an exhaustive qualification of this type of video/image processing and the testing of same is beyond the scope of this program.

2.2.1: Carborne Components

We built and/or procured each of the on-board components.   They are shown pictorially below in FIGURE 1:

SIL4 Dual – Purpose Vehicle Platform
• Compact Safety Platform (Powerful SIL-2 to -4)
• Vehicle Monitoring Platform
• Designed to En50155 Environemental
• Designed to EN50126/128/129 Safety Std.
• (32) Train-line Inputs
• (4) Tachometer Inputs
• (4) Analog Inputs
• (10) Safety Outputs for TO/ATP/ATS/PTC/Brake Control Functionality.
• Dual Ethernet

VCM-4000 Vehicle COMMS Module: Provides high computational power with powerful connectivity:
•   (2) Wi-Fi Ports (802.11 a/b/g/n SMA connector)
•   (1) 3G cellular networks (HSUPA/HSDPA/UMTS/GPRS modem via SMA),
•   (2) Gigabit Ethernet Ports
•   (1) High performance GPS Port (50 channels Galileo ready, SMA connector)
Other Interfaces:
•   (10) Discrete Opto-isolated Digital Inputs + (5) Discrete Opto-isolated Digital Outputs
•   (1) RS-232 Serial Port + (2) USB Ports (2x USB 2.0)

Multi-Band Antenna:
• **Cellular** (694-894;1650-2000; 2100- 2700 MHz)
• **WiFi:**   2.4 & 4.9 - 6.0GHz
• **GPS:**   1575 MHz
• -40C to +85C
• Compact 4.2" L x 3.2" H

Mass Storage Device
• DVR Function
• Time Stamp/Sync
• Search Functions
• 320GB
• -40C to +70C
• Wireless access

Train Operator Display (TOD)
• Approaching Highway Crossing
• Alarm Monitors
• Data Entry (Operator, Train #,
• Indication of Perf. Degradation
• Status / Op Conditions
• Real-time data
• VMS initiated subsystem test

Accelerometer:
• +/- 0.5g (10.9684 mph/s)
• Non-linearity: 0.1%
• T Sensitivity< 200ppm/C
• Temp Range: -55 C to +95C
• MIL-STD 202, Method 112

Crash-Hardened Memory
• IEEE1482 Compliant
• FRA compliant
• 1, 2, 4, 8, 16 GB
• Wifi Accessible

FIGURE 2.1: Car-borne Systems – Stage 2

Specifically we implemented features from three (3) of SIL4 Systems existing Carborne Vehicle Platforms that offer a variety of car-borne features that could be utilized in the final system . They are:

> Vehicle Monitoring Platform (VMP) is for Event Recording / train data storage
> Vehicle Communications Platform (VCP) for GPS, 3G and WiFi communications
> Train Operator Display (TOD)

They are shown above in figure 2.1 as well and a highlighted summary of performance features.

We had a challenge in evaluating various antenna options to find a compact set of antenna that could be easily mounted onto a Light Rail vehicle and accommodate the various frequencies and functions of our requirements.

We chose a multi-band Antenna featuring 3-elements in one antenna radome to accommodate cellular, GPS and WiFi communication.

The first antenna element handles the full cellular spectrum with an extremely wide band which can cover: LTE at 700 MHz as well as the established 850/1900 GSM/CDMA bands, 1.7/2.1 AWS bands and WiMAX 2.5 all on a single board. And this antenna is ready for any 4G rollout but is also compatible with earlier generation such as GPRS.

The second antenna element, covers 2.4/5 dual-band WiFi. Alternatively, the second element can be used for other specialized applications such as: Public Safety coverage at 4.9 GHz, Military at 4.4 GHz or DSRC at 5.9 GHz.

The third antenna element covers GPS band at 1575 MHz. The antenna is enclosed in a 4.2"D x 3.2"H (107 mm x 81 mm) weatherproof radome, and supplied with all mounting hardware and a sealing gasket. The radome is available in either black or white. The antenna is available in either surface mount or magnetic mount.

Multi-Band Roof Antenna - Features	
Roof-Mount Package:	Rooftop Multi-Band Antenna
Multi-Band Antenna:	
	694 - 894 MHz. 2dBi
Cable 1 (Cellular):	1650-2000 MHz, 5 dBi
	2100-2700 MHz, 3 dBi
Cable 2 (WiFi and Public Safety):	2.4 & 4.9-6.0 GHz, 5 dBi
Cable 3 (GPS):	1575.42 +/- 2 MHz, LNA 26dB,5 dBi nominal RHCP, Antenna
Compact, Rugged Package: Vehicle-Ready Performance	
Operating Temp. Range	-40° C to +85° C
Shock & Vibe:	IEEE1478, EN 61373, MIL-810G, TIA 329.2-C
Water Ingress:	IP67, IPx5
Compact Profile:	4.2"D x 3.2"H (107 mm x 81 mm)

FIGURE 2.2: Car-borne Multi-Band Antenna

2.2.2: HIGHWAY-RAIL CROSSING (HRC) Components:

The Crossing components have now been finalized. This consists of a super-set of features that can be tailored to the particular crossing / incident type or perceived hazard scenario and consequent mitigation.

They consist of the following components as listed here and depicted below:
- An outdoor surveillance camera – visible and IR range
- A WiFi Transmitter/Receiver with Input/Outputs for interfacing/controlling features at the Crossing
- A light/strobe for visual warning, as well as, perhaps illuminating the scene, just prior to train arrival.
- An alarm with flasher
- An IO device for expanded capabilities including interfacing with existing crossing equipment and / or syncing with surface traffic signaling.
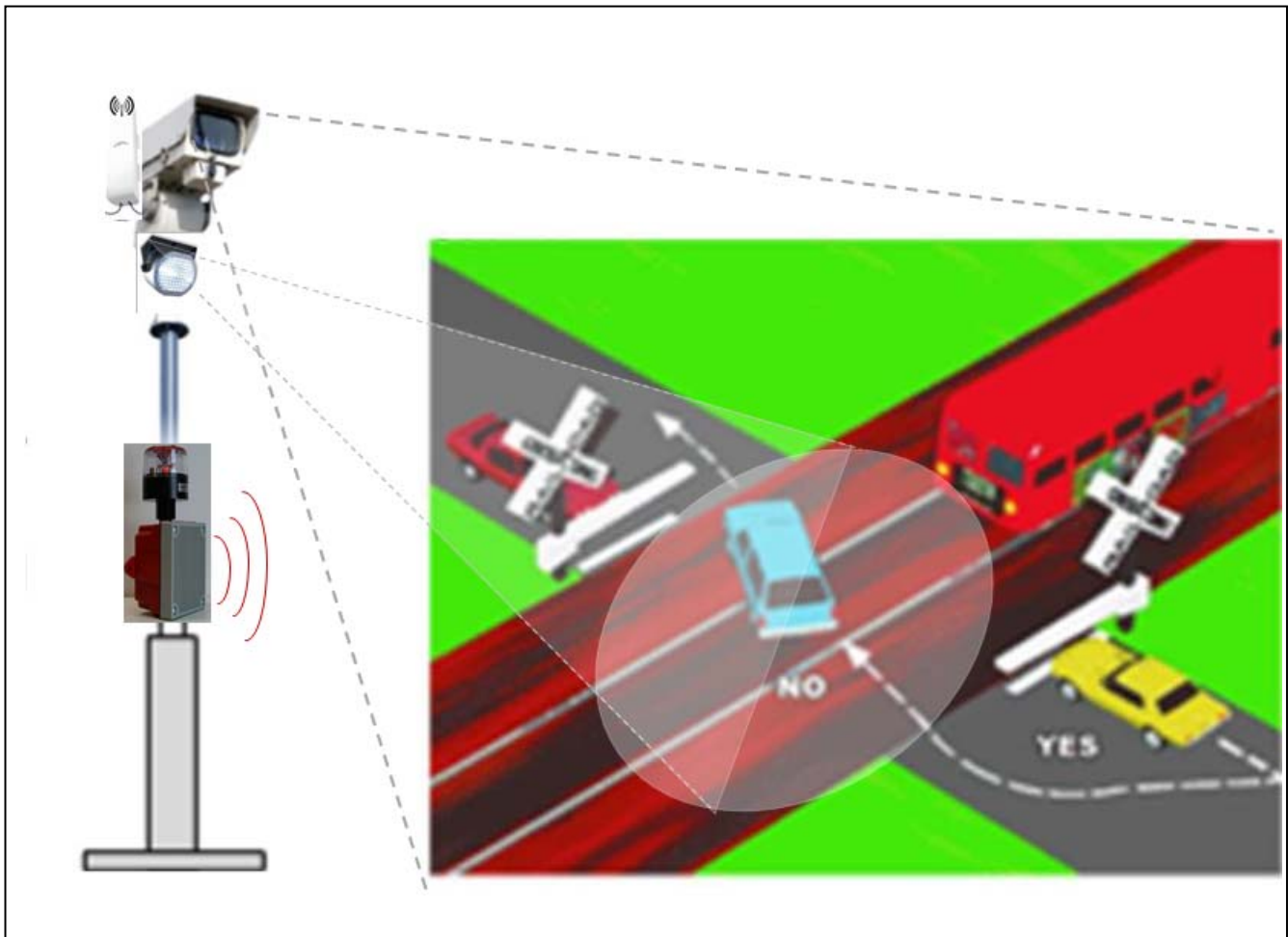
FIGURE 2.3: Highway-Rail Crossing (HRC) Components

It should be noted that we selected low-power/efficient devices for the instance when the HRC package is mobile. The camera used less than 10W, the 5.0GHz transmitter/receiver/antenna uses less than 8W of power, thus typically, the minimum power needed at HRC is 15W. This is well within the range of most single-panel solar arrays in most settings. Of course, if lighting is use this will significantly increase the power budget but at a temporary work sight an audible alarm will suffice.

Highway Crossing Transmitter/Receiver	
5GHz High Power TDMA Station	
Compact Package:	11.6" x 3.1 x 1.2" (30cm x 8 cm x 3 cm)
Light Weight:	0.9lbs (0.4kg)
Rugged Outdoor Package:	UV Stabilized Plastic
Operating Temp. Range:	-30°C to +80°C
Operating Humidity:	5 to 95% condensing
Shock and Vibe:	ETSI300-01901.4
5GHz High Power TDMA Station	
Frequency Range:	4.9-5.9 GHz
Gain:	14.6-16.1 dBi
Polarization:	Dual Linear

FIGURE 2.4: Highway-Rail Crossing (HRC) Components

General	
Processor:	TI DaVinci Series DSP
OS:	Embedded Linux
User Interface :	WEB, CMS(DSS/ PSS), ICRSS, NVR
Camera	
Image Sensor:	1/3" 2.0 Megapixel SONY progressive scan Exmor CMOS
Effective Pixels:	1920 (H)x1080(V)
IR Feature:	Support ICR True Day/Night w/Built-in IR Distance: up-to 60ft
Electronic Shutter:	Auto/Manual, 1/60~1/10000s
Mini. Illumination:	0.1LUX/F1.6(Color), 0.01LUX/F1.6(B/W), 0Lux(IR ON)
Signal Noise Ratio:	>50dB
Video	
Video Compression:	H.264E/MJPEG/JPEG
Image Resolution:	1080P(1920x1080)/720P(1280x720)/D1(704x480)
Bit Rate:	56Kbps~8192Kbps
Audio	
Audio Compression :	G.711a / G.711u / PCM
Bidirectional Talk:	1 channel, 3.5mm JACK LINE IN
Bit Rate:	128kbps/64kbps/10.2kbps
Network	
Ethernet:	RJ-45 (10/100Base-T)
Network Functions:	HTTP, TCP/IP, ARP, IGMP, ICMP, RTSP, RTP, UDP, RTCP, SMTP, FTP, DHCP, DNS, DDNS, PPPOE, UPNP, NTP, Bonjour, SNMP.
Rugged	
Ingress Protection:	IP66 Weatherproof, IK10 Vandalproof
Operating	14°F~140°F / -10°C~+60°C, 10%~90%
Low Power	< 10W

306.7

195.8

TITLE: TRB Crossing Camera
Drawing: Carl E. Conti
Date: 14-NOV-2012
NOTES:

S1L4 SYSTEMS
Embedded Safety & High Reliability Computing Platforms

THIS DOCUMENT AND ITS CONTENTS ARE THE PROPERTY OF S1L4Systems, Inc. and furnished to you on the following conditions:
1.   No right or license in respect to this document or its contents is given or waived in supplying this document to you.
2.   This document or its contents are not to be used or treated in any manner inconsistent with the rights or interests of S1L4Systems, Inc or to its detriment.
3.   And are not to be copied, reproduced, disclosed to others, or disposed of except with prior written consent.

FIGURE 2.5: Highway-Rail Crossing (HRC) Components

2.3: Task 6: Software Development

18

Concurrent with other tasks, SIL4 engaged in software development and component programming and configuration to facilitate testing and assure system functionality. During Stage 2 the SIL4 team engaged in several such software efforts. They are listed here along with achievements:

2.3.1: Vehicle Monitoring Platform (VMP)/Event Recorder Software were implemented and all IEEE1482-1999 Spec Requirements were validated including these key operational ones:

+ Power-On Self-Tests   + Each signal recorded 1/sec   + Watch-dog timer check
+ Program CRC check   + Minimum 96 hrs data Record   + Data Check (24 hr cycle)
+ Sample rate: 20ms   + Real-Time Clock check   + Controlled Shut-down

2.3.2: On-Board Comms Module (VM-4000) software development was engaged in:

+ Configuring TCP/IP Port   + Cellular Port configuration and Testing
+ Programming GPS Data Transceiver   + Static and Dynamic Testing

2.3.3: DVR Module software development /configuration including the following achievements:

+ DVR Record and Loop Testing   + Analog Port Configuration
+ DVR Record Retrieval   + GPS feature

2.3.4: HMI (Human-Machine Interface) software development /configuration including the following achievements:

+ GUI Interface   + Streaming Video Window
+ Indicator Window   + GPS Map feature

2.3.5: Vehicle Simulator software development of all Inputs and GUI Panel:

+ GUI Interface (Appendix B)   + Synchronous operation
+ Event Recorder Inputs   + Preliminary Testing and Validation

2.4: Task 7 - Field Trial Prep II

Co-incident with tasks 5 & 6 and at the beginning of month 5 of the program - SIL4 investigators met with the co-operating authority (GCRTA) and discussed the final installation and test details.

As was determined in the first TRB meeting, and confirmed in subsequent meetings and conversations - the area of interest, where incidents and close calls were most prevalent, was in the GREEN Line / Shaker Square area where the Green and Blue Line diverge. This would include Coventry and Southington heading east, as well as Drexmore and S. Woodward Crossings going south on the Blue Line as shown and highlighted below.

The GCRTA Rail map shows these stations/crossings in the context of the entire rail property.
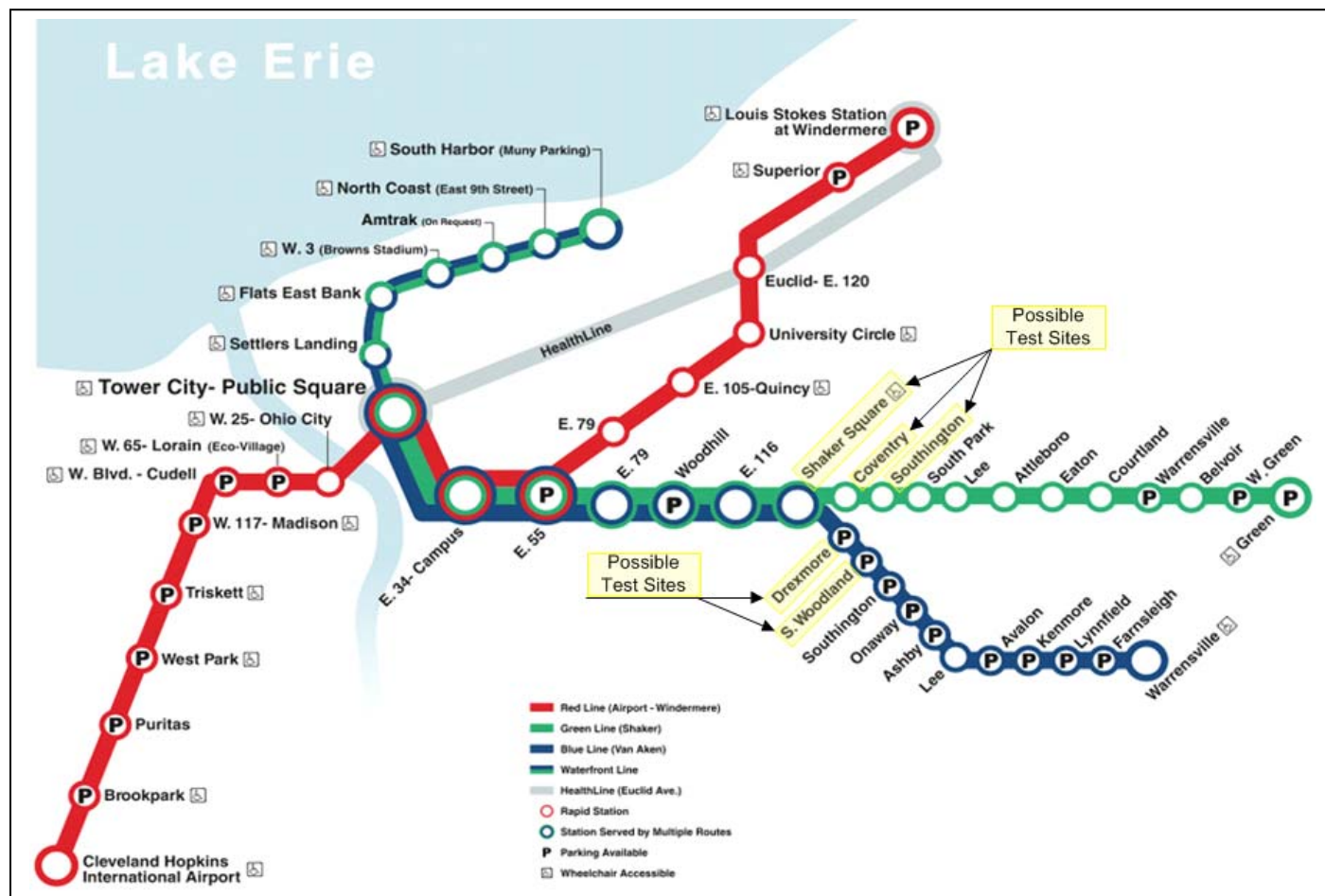
FIGURE 2.6: GCRTA Rail Transit Map

2.5: Task 8 - Test Planning

A Draft Test Plan was written outlining the car-borne and crossings installations and Field Testing. It is outlined here. We will install the Car-borne package per Appendix A and outlined in Stage I Report. The Crossing equipment is described above however the final packaging of it is still under development. Potential installation sites are presented here showing and detailed aerial view of the crossing gleaned from Google™ Earth and a ground view photo of the crossing taken at the site during our visit.

Our HRC Crossing electronics package can be mounted on any of the utility/catenary poles shown in the photos shown in the subsequent crossing survey and powered from 120vac or 24VDC battery, as needed.

We made a trip to the along the Green-line to the Shaker Square area and identified the various Crossings of interest being Shaker Square where the Green and Blue Line diverge and also Coventry, Southington; South Park; Lee etc. heading east as well as Drexmore, S. Woodward and Southington on the Blue Line.
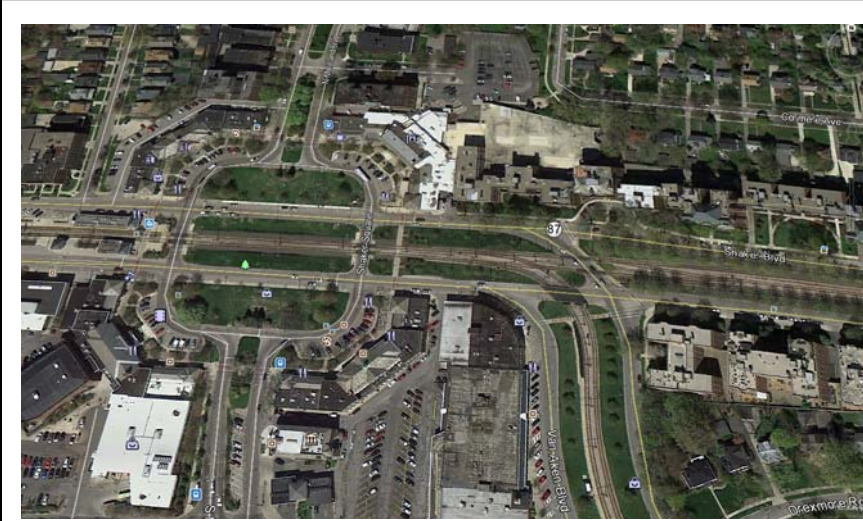
Figure 2.7a: Shaker Square (3) Crossing - Aerial View (Google Earth)
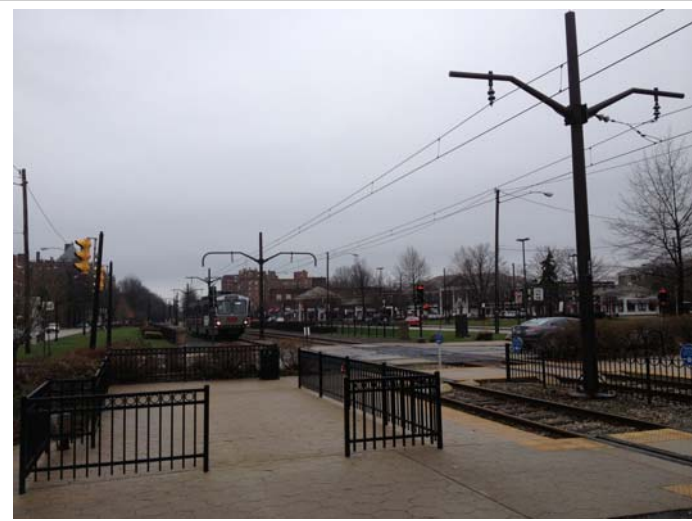
Figure 2.7b: Shaker Square - West most Crossing

Figure 2.7c: Shaker Square Center Crossing

Figure 2.7d: Blue Line Turn-out toward Drexmore

During Stage 3 we researched and developed needed tools and methology for mapping any section of track as well as software algorithms to use Speed/tachometer data to fill in position in formation when GPS is lost/dropped out and also accelerometer data to check / correct data during spin (accel > 3.5mphps) or slide (decel >-3.5mphps).

Figure 2.8a: Shaker Square GPS Mapping of Blue Line turn-out   **Figure 2.8b**: Shaker Square GPS Mapping of Green Line straight-through run
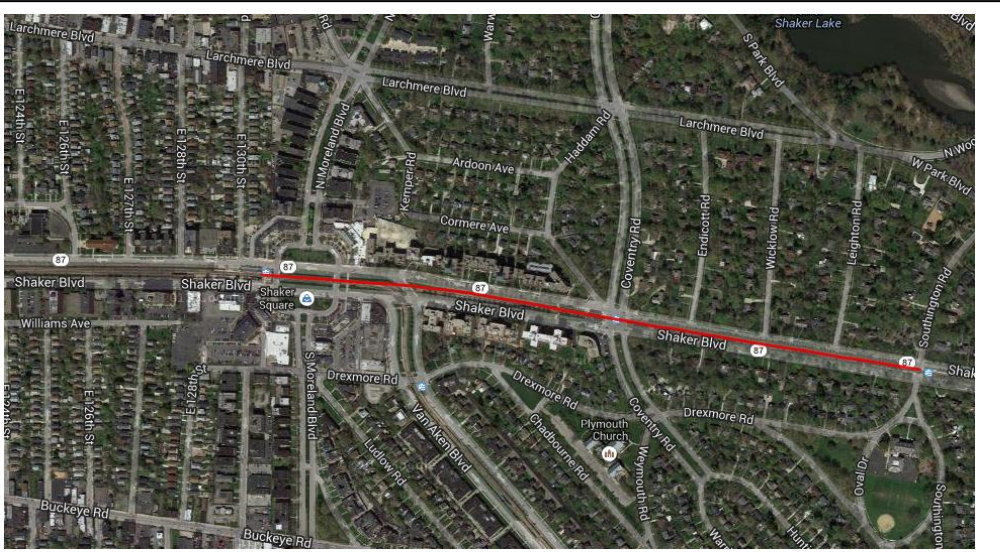
We've developed accurate methods and tools to "map" and track section, line or entire route.   Here is a sample of the above routes GPS mapping data. Each point is approximately 4 inches distance from the previous point.

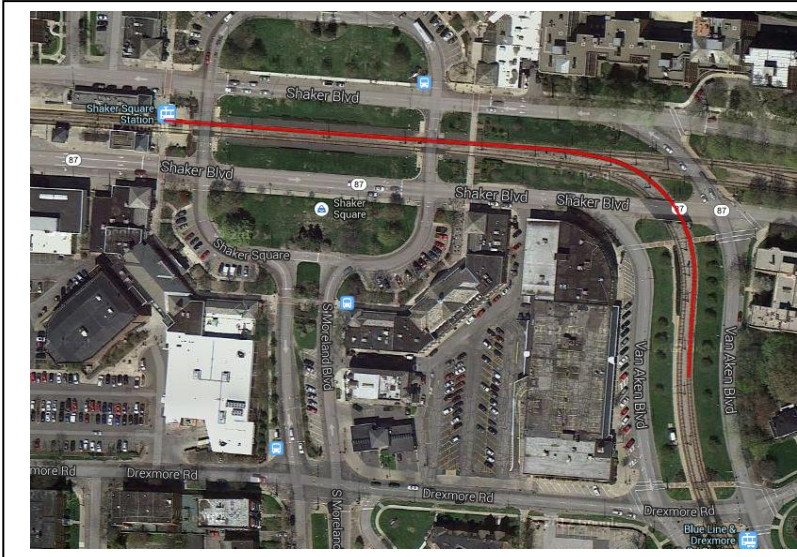| Shaker Square - BlueLine turn-out (GPS mapping)		Shaker Square - GreenLine Straight thru (GPS mapping)	
41.483755,-81.588776	41.483748,-81.588754	41.483946,-81.591453	41.483944,-81.591432
41.483755,-81.588775	41.483747,-81.588753	41.483945,-81.591452	41.483944,-81.591431
41.483754,-81.588774	41.483747,-81.588752	41.483945,-81.591451	41.483944,-81.591430
41.483754,-81.588773	41.483747,-81.588751	41.483945,-81.591450	41.483944,-81.591429
41.483754,-81.588772	41.483746,-81.588751	41.483945,-81.591449	41.483944,-81.591428
41.483753,-81.588771	41.483746,-81.588750	41.483945,-81.591448	41.483944,-81.591427
41.483753,-81.588770	41.483746,-81.588749	41.483945,-81.591447	41.483944,-81.591426
41.483753,-81.588769	41.483745,-81.588748	41.483945,-81.591446	41.483944,-81.591425
41.483752,-81.588768	41.483745,-81.588747	41.483945,-81.591445	41.483944,-81.591424
41.483752,-81.588767	41.483745,-81.588746	41.483945,-81.591444	41.483944,-81.591423
41.483752,-81.588766	41.483744,-81.588745	41.483945,-81.591443	41.483944,-81.591422
41.483751,-81.588765	41.483744,-81.588744	41.483945,-81.591442	41.483944,-81.591421
41.483751,-81.588764	41.483744,-81.588743	41.483945,-81.591441	41.483944,-81.591420
41.483751,-81.588763	41.483743,-81.588742	41.483945,-81.591440	41.483944,-81.591419
41.483750,-81.588762	41.483743,-81.588741	41.483945,-81.591439	41.483944,-81.591418
41.483750,-81.588761	41.483743,-81.588740	41.483945,-81.591438	41.483943,-81.591417
41.483750,-81.588760	41.483742,-81.588739	41.483945,-81.591437	41.483943,-81.591416
41.483749,-81.588759	41.483742,-81.588738	41.483945,-81.591436	41.483943,-81.591415
41.483749,-81.588758	41.483742,-81.588737	41.483945,-81.591435	41.483943,-81.591414
41.483749,-81.588757	41.483741,-81.588736	41.483944,-81.591435	41.483943,-81.591413
41.483748,-81.588756	41.483741,-81.588735	41.483944,-81.591434	41.483943,-81.591412
41.483748,-81.588755	41.483741,-81.588734	41.483944,-81.591433	41.483943,-81.591411

2.6 Component and System testing, Data Collection and Analysis

SIL4 investigators tested various aspects of the Car-borne package and HRC components and system interfaces per the test plan to assure system functionality.

2.6.1 COMMUNICATIONS TESTING (Streaming Video) – Static Testing:

To test the communications we needed a long term Static test of an outdoor camera set-up that would preferably be monitoring a relevant scene. A fixed-position camera located at a Highway-Rail Crossing (HRC) with GPS locator and streaming video via WiFi to a receiver and Human-Machine Interface (HMI).

- A Car-borne DVR to capture the live information.
- HMI (Human-Machine-Interface) on board our Mobile Station (Test Vehicle)
    1. HMI displaying Date: Time information.
    2. HMI displaying the Live Video feed of the Crossing.

It just so happens that we have a Highway-Rail Crossing behind the SIL4 offices and so we were able to use that as our test-bed/target.

Figure 2.9a: Static Test Site - rooftop behind SIL4 Offices   **Figure 2.9b:** Camera-view from Static Test Site (no zoom)

Figure 2.9c: Static Test Camera (mounted on roof - 3500 yards from HRC)
NOTE: Static Test Camera image in medium-snow storm (actual installation – camera will be much closer)

23

Figure 2.10a: Approaching Test Vehicle Operators View; HRC View and GPS Positioning

Figure 2.10b: Approaching Test Vehicle Operators View; HRC View and GPS Positioning

We installed this camera on February 28th and kept it running for approximately 14 weeks of continuous operation without incident or glitch of any kind.

2.6.2 Antenna Static Range Testing (Streaming Video)

To test the communications range - we needed a location that provided unobstructed line-of-sight range of ½ mile or more.   We went to Bridgeville, PA and was able to measure ~0.55 miles range and achieve signal:

- A fixed-position camera and antenna located at Point A.
- A fixed-position antenna and video monitor and power meter located at Point B.

Figure 2.11a: Antenna Range Test Location (~0.55 miles or ~3000ft)

Figure 2.11b: Range Test – View from Point A   **Figure 2.11c:** Zoom view of Point B (from Pt. A)

2.6.3: Static Testing Summary

The Static testing has been going on for some 8 weeks with good results. We were able to mount a fixed camera and continually monitor a Highway-Rail crossing that is located behind the SIL4 offices. While the camera was some 350ft away from the intersection – we selected a camera with pan/tilt/zoom (PTZ) features and were able to zoom in and simulate nearly a camera at the intersection. We were also able to test our rugged DVR and its recording features including recording only on some variably set level of motion. We were able to successfully test the night-vision aspect of the camera and found it to be very usable/adequate even at this distance. This test is on-going however we were able to achieve all of the operational testing desired.

With the VCM-4000 COMMs module and multi-band antenna we have successfully streamed video from the camera (hardwired to the RJ45 Ethernet port), to the WIFI output of the VCM-4000 (through internal port-forwarding. The steam is then available to any device logged onto the VCM-4000 WIFI connection. The stream used the RSTP (Real Time Streaming Protocol) on an assigned port from the VCM-4000.

Regarding antenna range testing after considerable testing under varying conditions – we drew the following conclusions:
- 5.0GHz antenna is adequate for line-of-sight usage up to 1 mile and perhaps beyond, otherwise repeaters are required.
- 5.0GHz antenna is adequate for ¼ to ½ mile with some obstructions (trees, bridges etc.) otherwise strategically places repeaters are required.
- Repeaters can adversely impact video streaming latency.
- 5.0GHz is less noisy band (at the time of writing) in most cases/installations.
- Buildings are considerable attenuators/obstructions.
- Sloping Terrain / earth blocking line of sight is a considerable attenuator/obstruction.
- 2.4 GHz may be more reliable with trees and foliage.
- New bands, equipment and solutions are evolving continuously and rapidly.

2.6.4: COMMUNICATIONS TESTING (Streaming Video) – Dynamic Testing:

To test the communications we need to construct a rather complex set-up wherein we wanted to show the following features/functionality:

- A fixed-position camera located at a Highway-Rail Crossing (HRC) with GPS locator and streaming video via DVR/3G cellular transmitter to the cloud/internet.
- A Mobile Cellular connection receiving the data (live video from the HRC)
- A Car-borne DVR to capture the live information.
- HMI (Human-Machine-Interface) on board our Mobile Station (Test Vehicle)
    1. HMI displaying Date: Time information.
    2. HMI displaying the Live Video feed of the Crossing.
    3. HMI displaying the Car-borne Operator's view (with an added camera).
    4. HMI displaying the moving position of the vehicle on a back-drop of a Terrain/Track Map.

We selected the following location because it gave us a quiet intersection where the surface road ran parallel to the Rail track so that our approaching Test Truck would be similar to an approaching train.
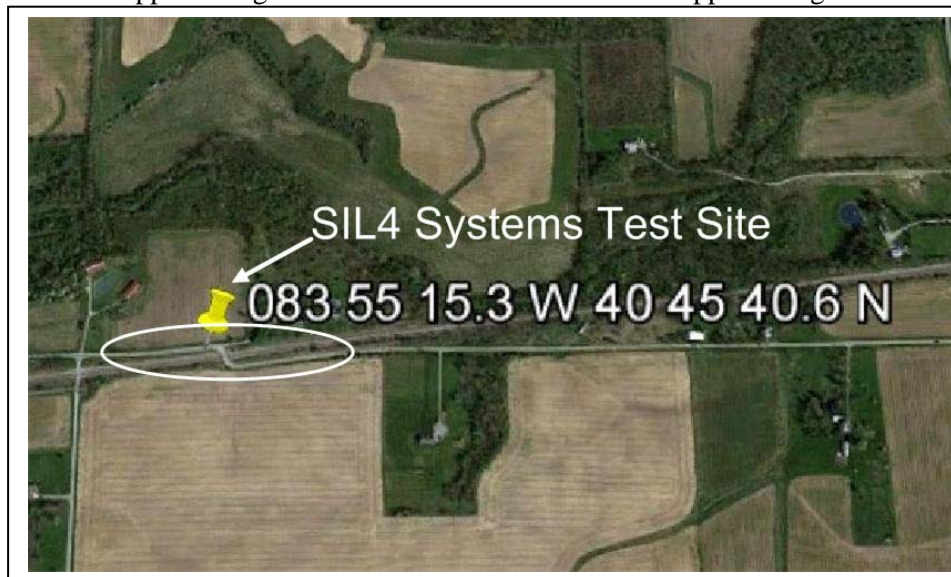
Figure 2.12a: Test Site

Figure 2.12b: Test Site with Test Vehicle planned path super-imposed.

Figure 2.13: Approaching Test Vehicle Operators View; HRC View and GPS Positioning

In this an all subsequent screen captures it should be noted key field on the Human-Machine Interface (HMI) screen captures. There are three (3) live/continually updated screens.

1. In the FULL SCREEN field you will see the Google-Map of the Rail Line and surrounding terrain. Included in that you can extract the GPS coordinates and other location information.

In the Lower right of the screen you will see two live/streaming camera feeds. They are:
2. On the LEFT - A camera looking out of the front test vehicle (OPERATOR VIEW)
3. On the lower RIGHT – A camera fixed as the HRC CROSSING (mounted here on the back of a pick-up truck).

We will be approaching on the lower road running parallel to the Rail Track, from right (east) to left (west). The position of the moving camera and the FIXED camera will be shown and continually updated on the live screens.

In subsequent screen captures, shown will be the position/scene updated on all screens as we approach, cross and pass beyond the rail crossing.

We also have a DVR video capture of the HMI screen capturing the test run live and can be made available upon request.

Figure 2.14: Approaching Test Vehicle now in HRC Camera View

NOTE: HRC Cam visible from approaching Test vehicle.   **NOTE**: Test vehicle visible from FIXED HRC Cam.

Figure 2.15: Test Vehicle in Crossing

Figure 2a: Approach

Figure 2.16: Test Vehicle passing through crossing

2.6.5: Dynamic Testing Summary

Dynamic Testing: Using a 3G/4G connection port on our Carborne COMMs package, we transmitted data for 1 hour on the sub-stream option at a configured rate of 220 kbps. The system automatically optimizes the image using resolution and frame rate to keep the data rate under the configured rate.

With the Mobile DVR, the cameras are connected to the DVR using analog inputs. The DVR records and controls the video and creates an IP output that can travel to a video server via WIFI, wired Ethernet, or cellular data. Tests with cellular data were done over a 1 hour period, streaming 2 cameras to the remote server with the DVR configured to optimize the data bandwidth by limited it to 200 KBS per camera. We are still awaiting actual bandwidth usage numbers from the Verizon cellular data system.

Section 2.7: Conclusions of Stage 2

Car-borne Package:

- **ANTENNA:** The multi-Band Wireless antenna will work for our purposes and provide WiFi, 3G cellular and GPS transceiver capabilities. It handles all 3 (3G, GPS and WiFi) bands of use including 2.4 and 5.0 GHz WiFi that is now here and becoming more prevalent.

- **EVENT RECORDER:** We will mount the EVENT RECORDER on the vehicle and monitor and record various signals such as Master Control Lever (MCL) and Direction Handle; Speed Codes; Brake Cylinder (BC) Pressure; Brake Pipe (BP) Pressure; Doors; Emergency Brake; Dynamic Brake; Horn; Bell; Headlights etc.

- **VEHICLE-HRC COMMS: WiFi v 3G cellular:** We investigated both means of communications and both can be fairly reliable and robust. Cellular has the infrastructure in place and growing but has bandwidth issues when it comes to streaming video (both real-time delay and cost which my require 2GB / hour vs. a typical data plan of 2GB per month). While cellular streaming can be optimized and turned ON/OFF depending on

30

"active time" where trains are "on approach" and can be turned off right after they pass the intersection, the data plan may still require 30GB / month per crossing.

Within our Dynamic Testing scenarios we used a 3G/4G connection port on our Carborne DVR, we transmitted data for 1 hour on the sub-stream option at a configured rate of 220 kbps. The system automatically optimizes the image using resolution and frame rate to keep the data rate under the configured rate. Other factors like light levels and amount of motion being transmitted might change the data rate, but the system will adjust to keep it under 220 kbps. So, the more motion the image contains, the lower the resolution and frame rate could go, resulting in worsening image quality. It is doubtful that motion will have much effect on the image quality.

So WiFi seems to be the winning preferred approach at this time.

WIFI - 2.4GHz v 4.9GHz v 5.0G WiFi:

2.4GHz: Wi-Fi networks have purposefully limited range to minimize interference. Home and commercial WiFi have become ubiquitous utilizing 802.11a/b/g/n. A typical wireless access point using 802.11b or 802.11g with a stock antenna might have a range of 32 m (120 ft) indoors and 95 m (300 ft) outdoors. IEEE 802.11n, however, can more than double the range.

Wi-Fi in the 2.4 GHz frequency block has slightly better range than Wi-Fi in the 5 GHz frequency block which is used by 802.11a and optionally by 802.11n. Outdoor ranges can achieve kilometer+ range through the use of high gain directional antennas at the router and remote device(s), within power limits set by local, state and Federal regulations, such as FCC Part 15 in the US.

We will utilize and test in this range for our initial testing. Our field tests have shown this to be a viable approach.

4.9GHz: 50 MHz of spectrum from 4940 MHz to 4990 MHz (WLAN channels 20–26) are reserved for use by public safety entities in the United States. It is unclear whether the 4.9 GHz (802.11y) Public Safety WLAN can or will be made available for this type of application. We will be watching the evolution and usage of this band but in essence 50 MHz of spectrum from 4940 MHz to 4990 MHz (WLAN channels 20–26) are in use by public safety entities in the United States. Within this spectrum space, there are two non-overlapping channels allocated, both with a width of 20 MHz. The most commonly used channels are 22 and 26.

5.0 GHz: In 2007 the FCC (United States) began requiring that devices operating on 5.250–5.350 GHz and 5.470–5.725 GHz was required to employ dynamic frequency selection (DFS) and transmit power control (TPC) capabilities. This is to avoid interference with weather-radar and military applications. In 2010, the FCC further clarified the use of channels in the 5.470–5.725 GHz band to avoid interference with Terminal Doppler Weather Radar (TDWR) systems. This statement eliminated the use of channels 120, 124, and 128. Channels 116 and 132 may be used, so long as they are separated by more than 30 MHz (center-to-center) from a TDWR located within 35 km of the device. We will use the VCM-4000 to acquire GPS location and a custom mapping program on our HMI to display the moving train and the upcoming terrain and Crossings.

We will continue to test both 2.4GHz and 5GHz solutions for the streaming video Wifi for HRC to Carborne communications.

Also we are finding also that a moving vehicle (approaching train) access point takes some non-trivial time to negotiate the "connection" with the "next" crossing (station/host) and we are looking at ways to predict/bound this time and methods of improving/shortening it. They include:

1. Various ways to configure nodes to simplify this negotiation time. (Static IP addresses; improved signal strength)

2. Repeaters that allow an implementation of a "mesh" network wherein all LRVs and HRCs are constantly connected to the network. While this takes a bit more infrastructure, it will also allow remote monitoring for all cameras.

Crossing Package:

- **ANTENNA:** The multi-Band Wireless antenna will work for our purposes and provide WiFi, 3G cellular and GPS transceiver capabilities for both our carrne and HRC applcation.

- **CROSSING COMMS and Interface Controller:** We will use the VCM-4000 to acquire GPS location at the crossing as well as IO interfacing to various devices such as the audio alarm, Strobe/Spot-light. It should also be notes that our Crossing package has WiFi cellular and wired IO and could interface with surface traffic PLCs/controllers to assist in syncing LRV and surface road motorist traffic movement.

- **SPOT-STROBE LIGHT:** We will mount the Strobe/Spot light on pole in the crossing w/ the audio alarm.

- **Overall HRC Packaging:** We will attempt to package all components in one enclosure however we need to provide for flexibility in that the position of the camera will be the primary driver for the location of the package as it needs to be placed in a location (approximately 15-30 ft in height)providing for proper field of view as well as Wifi antenna location be a secondary concern for maximum range of coverage.

The following is a summary of desired "features" with various "implementations" to achieve the associated "impact".

FEATURE	HRC Safety System IMPLEMENTATION (options)	IMPACT
Active System – Alerts Operator	* Visual Display in Cab of Approach Crossing	Improved alertness/response time of operator
	* Optional Alert at some set distance	
Active System – Alerts Trespasser/worker	* Visual Alert of Spot light set to turn-on at either a set "distance" or "arrival-time"	Improved alertness/response t of person at risk
	* Visual Alert of Strobe immenant "arrival".	
Improved alertness/response time	* Visual Display of Approach Crossing	Actively alerts operator and pedestrian / motorist / worker.
	* Optional Alert at some set distance	
Active System – Applies Brakes	* Visual Display of Approach Crossing can have smart "HRC motion/activity" sensing SW that can alert the operator/apply brakes (ala ATP)	Actively alerts operator then applies brakes
	* Visual Display of Approach Crossing can have smart "HRC occupy" sensing SW that can alert the operator/apply brakes (ala ATP)	
Adaptive – works only when train approaches	* GPS location of Train and all Crossings and speed provides a constantly updated "arrival" time that can be used to trigger various features both on the LRV and in the HRC.	Avoids false triggers
	* GPS location of Train and all Crossings - it is conceivable that the approaching train can report it's speed to the HRC and that equipment could calculation "arrival" time.	
Comprehensive Record	* Event Data Recording on LRV.	Records events on the train and in the crossing.
	* DVR / video recording on LRV.	
	* DVR / video recording at HRC.	
Adaptable / Portable	* HRC Package can be mounted on Cart and Battery-operated for mobile/remote "work area" applications.	Can be set-up in temporary work areas.
	* HRC GPS reports location to approaching train and train can automatically adapts without prior set-up (if required)	

Table 2.1: Program Features, Implementations and Impacts Summary

It is recognized that testing to observe measurable safety improvements including those in which we would seek to change the behavior of the pedestrian/motorists in a particular crossing, would likely suggest a prolonged test / data collection activity outside the scope of this program. That said, we seek to demonstrate the various features/capabilities that can be brought to bear on this particular application and provide for a "heads-up"/advance view of the crossing by the operator as well as means for he/she to interact with the crossing in a more dynamic, real-time way.

SECTION 3: Stage 3 Results

3.1   Task 10: Pre-Trail Test Plan

SIL4 will wrote a Pre-Trial test plan and also conducted specific car-borne package tests; communications tests and HRC component /system tests in order to de-risk the trial installation and subsequent test trial. We performed them on the streets of Mt. Lebanon, PA and along the light rail corridor behind our facility.

3.2   Task 11: Field Trial Preparation — Stage 3

SIL4 investigators will do a final review of the field Trail installation and test in preparation for installation of equipment, pre-test qualification/verification testing and final Trial Test plan.

The pilot design system, including COTS components, were mounted in its test carrying case, tested and and tweaked for maximum performance. SIL4 investigators ran simulated field test will the car-borne package mounted on a motor vehicle to test dynamic performance (range and sensitivity) of the communications system.

3.3   Task 12: Field Trial Verification and Validation Testing

The pilot design system COTS components will be further tested and packaging tweaked for field durability. SIL4 investigators ran simulated field tests with the car-borne package mounted on a motor vehicle to test dynamic performance (range and sensitivity) of the communications system.

We then mounted the IP camera antenna out of the window of our office and traversed Washington Road and took data.   Below are pictures of: the antenna from the vehicle; a camera view from inside the office.
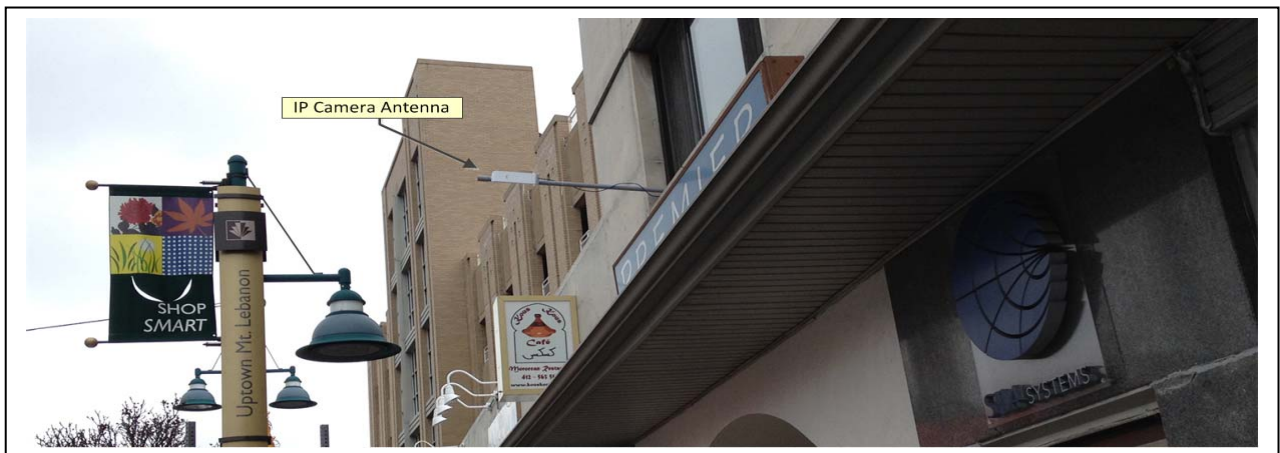
Figure 3.1: Streaming Video Antenna mounted outside the SIL4 Offices

Figure 3.2: Camera Streaming Video (snapshot) of its antenna from inside SIL4 Offices

We mounted the Mobile/car-borne antenna in a test vehicle and drove in the area taking data.

34

Figure 3.3: Mobile platform test with SUV–mounted antenna

Figure 3.4: Verification test route from SIL4 Offices (669 Washington Road – Rt.19 and south)

3.4   **Task 13: Field Installation**   GCRTA has limited us to their Test Track for these test runs so most of the runs will be in the test track.

3.4.1   **Task 13: Field Installation – Carborne Package**

Below is shown the actual equipment and functional description of the Carborne components.

SIL4 Dual – Purpose Vehicle Platform
- Compact Safety Platform (Powerful SIL-2 to -4)
- Vehicle Monitoring Platform
- Designed to En50155 Enviromental
- Designed to EN50126/128/129 Safety Std.
- (32) Train-line Inputs
- (4) Tachometer Inputs
- (4) Analog Inputs
- (10) Safety Outputs for TO/ATP/ATS/PTC/Brake Control Functionality.
- Dual Ethernet

VCM-4000 Vehicle COMMS Module: Provides high computational power with powerful connectivity:
- (2) Wi-Fi Ports (802.11 a/b/g/n SMA connector)
- (1) 3G cellular networks (HSUPA/HSDPA/UMTS/GPRS modem via SMA),
- (2) Gigabit Ethernet Ports
- (1) High performance GPS Port (50 channels Galileo ready, SMA connector)

Other Interfaces:
- (10) Discrete Opto-isolated Digital Inputs + (5) Discrete Opto-isolated Digital Outputs
- (1) RS-232 Serial Port + (2) USB Ports (2x USB 2.0)

Multi-Band Antenna
- GPS & Multi-Freqs
- 694 - 894 MHz
- 1575 MHz
- 1.7 – 2.7 GHz
- 4.9 - 6.0 GHz

Train Operator Display (TOD)
- Approaching Highway Crossing
- Alarm Monitors
- Data Entry (Operator, Train#,
- Indication of Perf. Degradation
- Status / Op Conditions
- Real-time data
- Extended Temperature
- High Reliability

Accelerometer:
- +/- 0.5g (10.9684 mph/s)
- Non-linearity: 0.1%
- T Sensitivity < 200ppm/C
- Temp Range: -55 C to +95C
- MIL-STD 202, Method 112

Figure 3.5: Refined Car-borne Package

The Carborne Package was equipment was packaged in a compact Case as shown below.

Vehicle Package Includes:

- GCRTA LRV CAB CONSOLE Simulator
- Vehicle Control /COMMS Platform
- Data Recorder;   Accelerometer
- Network DVR
- GPS / WiFi Antenna

all mounted in one Industrial Brief Case.

(Only 110vac interface needed)

Figure 3.6a: Portable Car-borne Package

The Carborne Package was equipment was packaged in a compact Case as shown below.

VCM-4000 - Vehicle Comms Module

IEEE Event Recorder /Safety Platform

Figure 3.6b: Portable Car-borne Package

On Friday 12/13/2013, we brought the System to the RTA maintenance shop for set-up / installation and then test runs. The Carborne Package installed and displaying streaming video from HRC camera.

3.4.2 Task 13: Field Installation – Highway Crossing Package

The following shows the fielded Highway-Rail Crossing (HRC) Package that is mobile and could be powered from a generator or battery pack on a trackside cart for mobile/temporary work area applications. :

HRC Control / COMMS Module:
Provides high computational power with powerful connectivity:
- (2) Wi-Fi Ports (802.11 a/b/g/n SMA connector)
- (1) 3G cellular networks (HSUPA/HSDPA/UMTS/GPRS modem via SMA),
- (2) Gigabit Ethernet Ports
- (1) High performance GPS Port (50 channels Galileo ready, SMA connector)

Other Interfaces:
- (10) Discrete Opto-isolated Digital Inputs + (5) Discrete Opto-isolated Digital Outputs
- (1) RS-232 Serial Port + (2) USB Ports (2x USB 2.0)

Powerful Integrated Antenna:
- 5GHz; 16dBi gain
- Beamwidth: 43° (H-pol); 41° (V-pol)
- PoE or 12VDC power
- IP66 Waterproof

Vandal Proof IP Camera:
- 2 Mega-pixel [(1920 (H) x 1080 (V)]
- 3.3 12mm lens
- Visible and IR sensitivity.
- 60ft range
- PoE or 12VDC power
- IP66 Waterproof

Powered by Honda Generator

Integral LED Flood Light Package

Figure 3.7: Highway Rail Crossing (HRC) Package

39

The following shows the fielded Highway-Rail Crossing (HRC) Package that is mobile and could be powered from a generator or battery pack on a trackside cart for mobile/temporary work area applications. We powered it on-site with a standard generator.
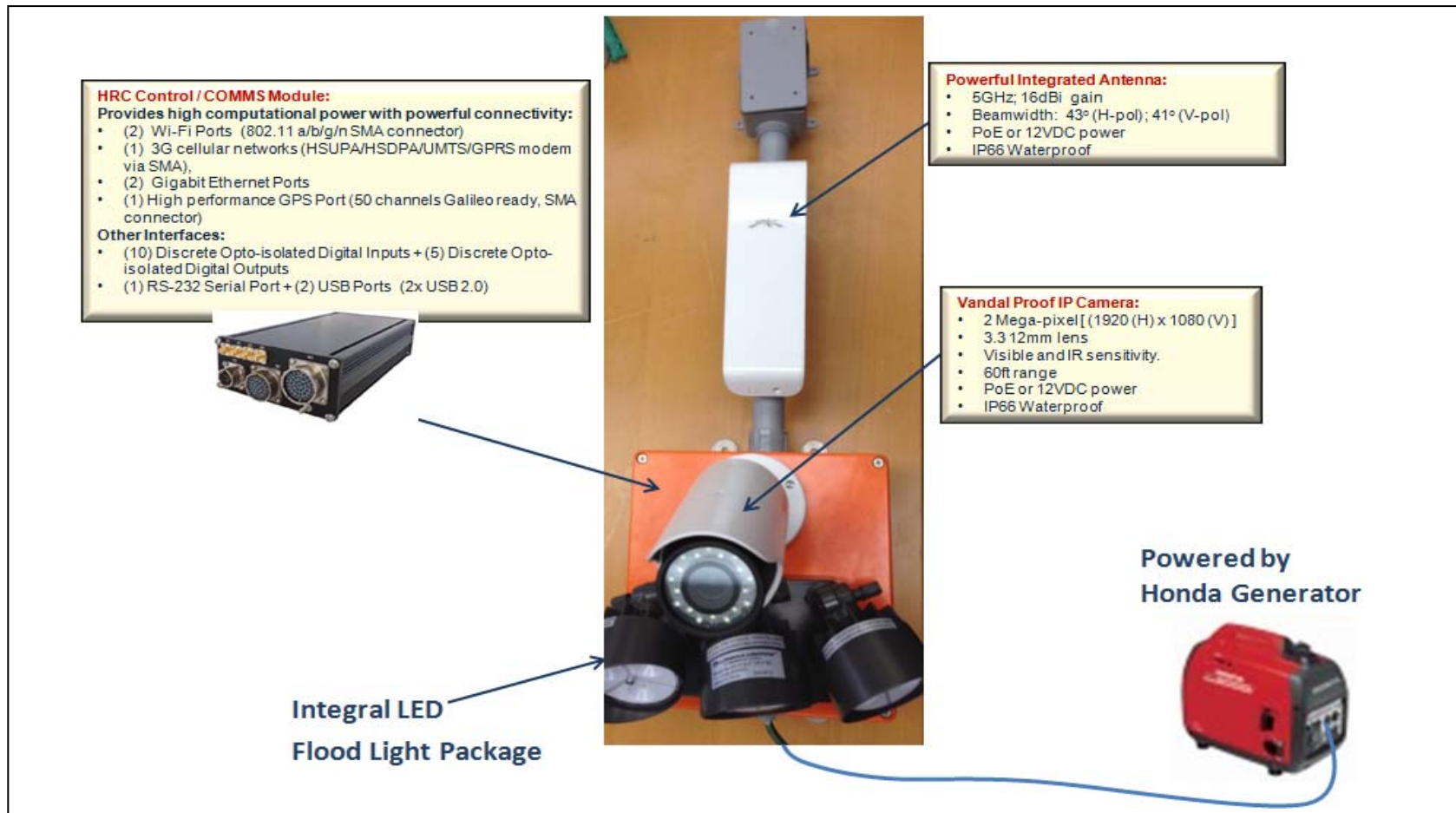

Figure 3.8: Highway Rail Crossing (HRC) Field Installation at GCRTA

The installation took less than 20 minutes and the package is a single integral unit weighing just under 10 lbs that easily mounts to any pole with standard metal band clamps or can easily be adapted to a battery cart for mobile / temporary work area site installation. The power required is 110vac or can be adapted for 12VDC power. It can communicate with wireless LANs in the area via WiFi (2.4 or 5.0GHz band). It also has cell network accessibility and GPS so it can report its location. The minimum set-up of a camera and transmitters consumes less that 15W typically making it easily deployed at a mobile site with a solar panel to power.
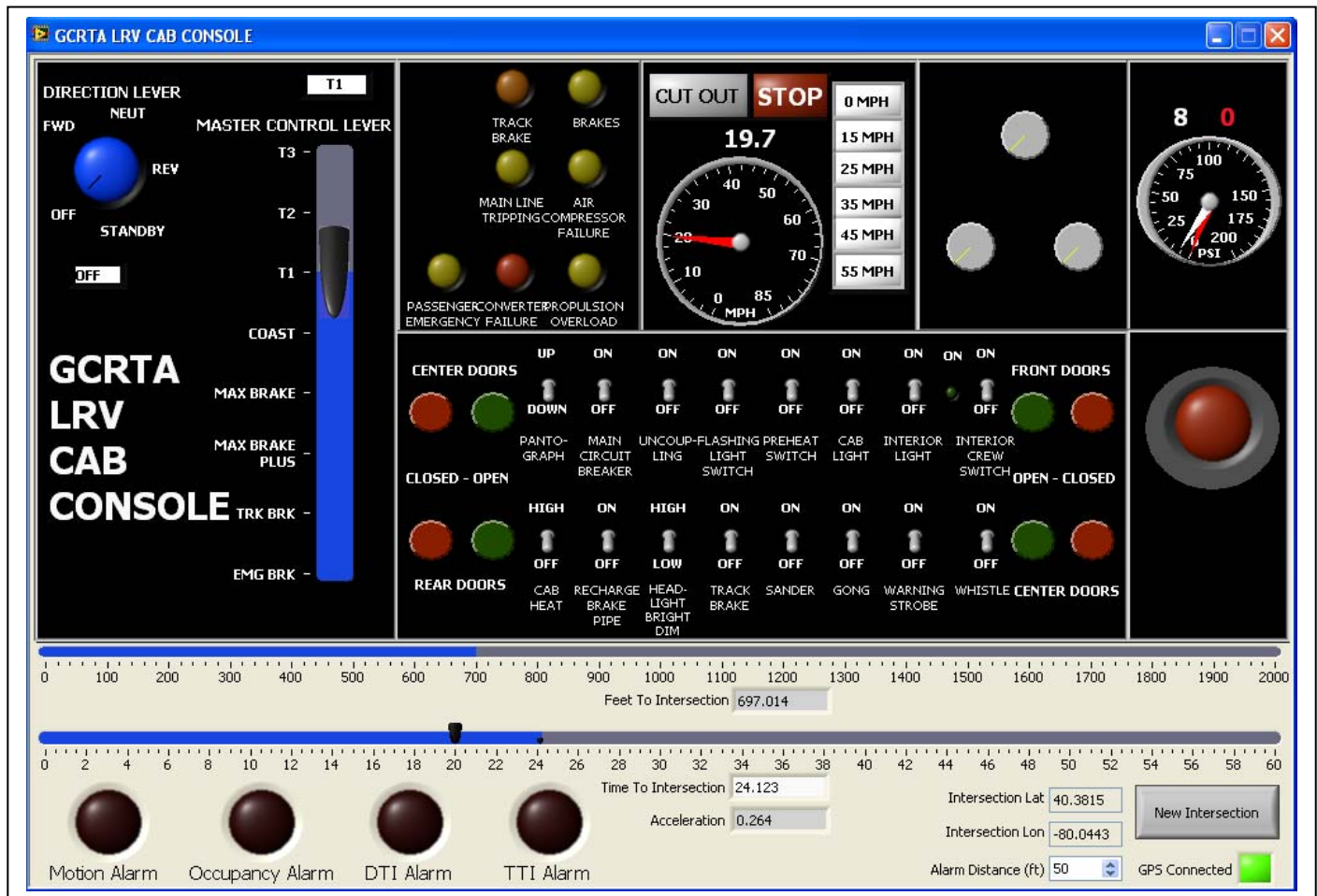
. The Carborne Package installed and displaying streaming video from HRC camera.

Figure 3.9: Streaming Video on carborne touchscreen monitor

3.4.3   Test Console

Figure 3.10: Test / Data Monitoring Console (upper carborne monitor)

The above Console is identical to the GCRTA Cab Console on the LRV that we test on. The Direction, speed, Master Controller position were monitored. Also we added the 2 horizontal meters on the bottom.

Once we installed the HRC package we pressed the button on the lower right of the console that took a GPS reading and stored it as the HRC location. We utilized 2 meters at the bottom of the console DISTANCE TO INTERSECTION (DTI) and TIME TO INTERSECTION (TTI). This allowed us to set alarms (audio and visual) at the intersection to trigger at either an approach distance (DTI) and/or an approach time (TTI).

Distance (feet) to Intersection/Crossing was set to 20 seconds which is a typical setting (20-30 seconds). The "actual/instaneous" reading varies dynamically with speed and distance to the intersection.

Therefore in the above sample screen capture:
- Master Controller is in the Throttle 1 (T1) position.
- Vehicle Speed = 19.7 mph
- Acceleration = 0.264 mphps
- Distance to Intersection = 697 feet
- Time to Intersection = 24.1 seconds

42

3.4.4 Demonstration Test Run

We made several live runs approaching the crossing set-up. Below is a typical car-borne data set.
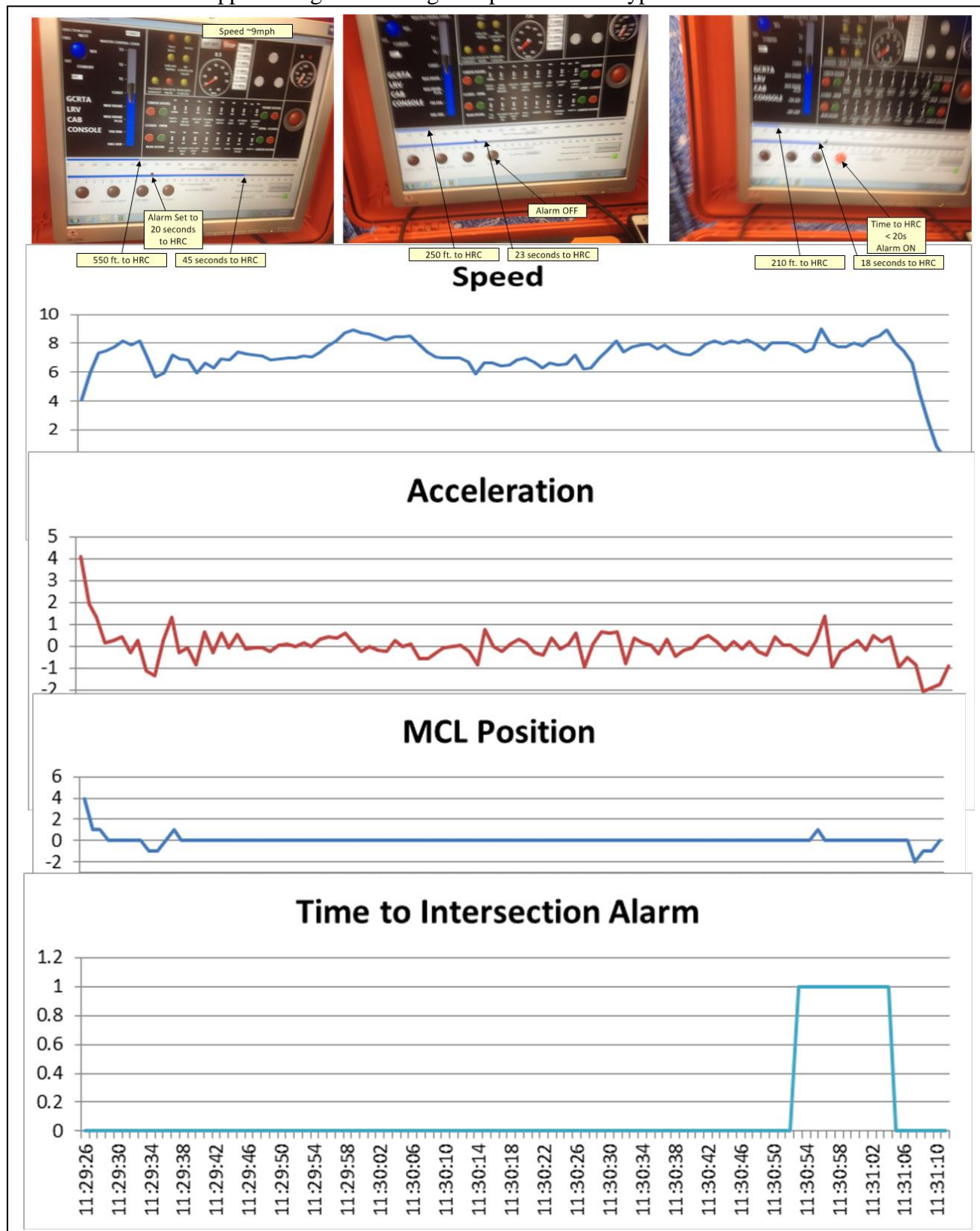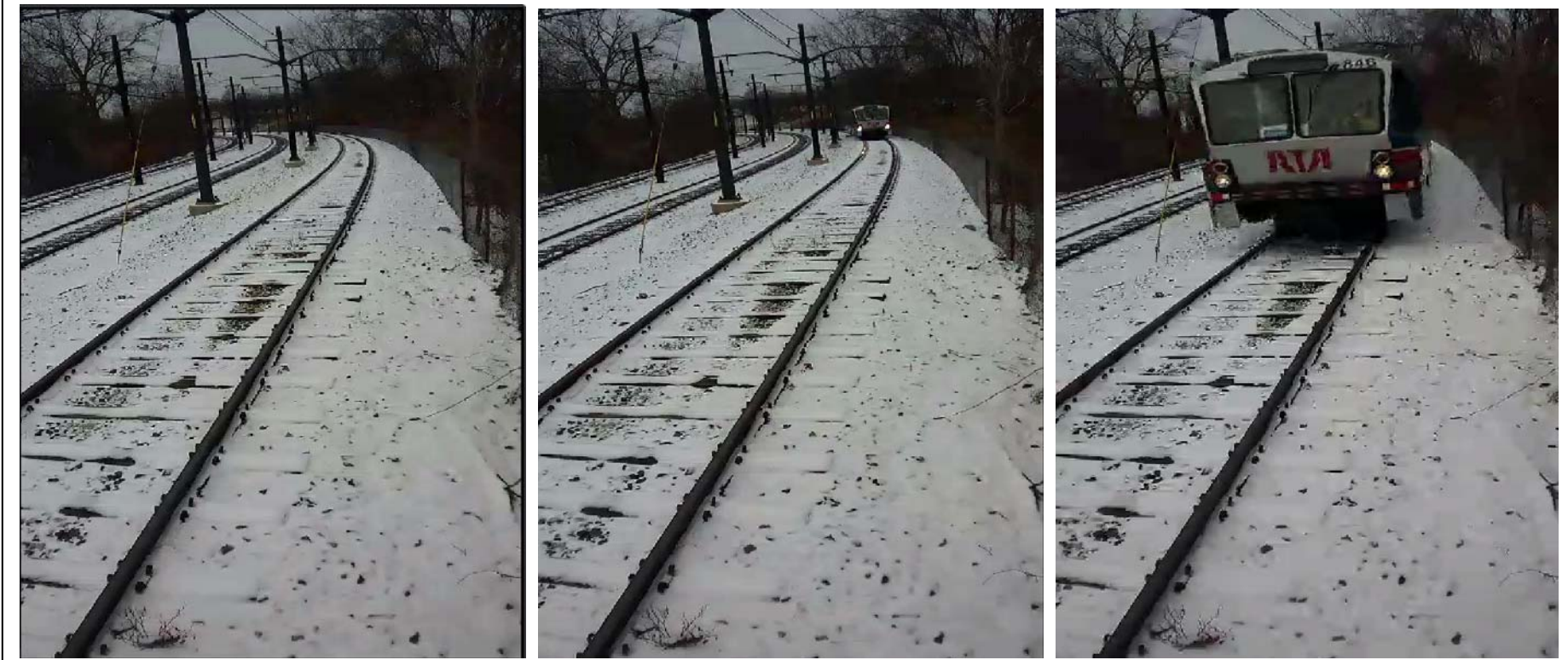

Figure 3.11: Sample Run data

The 3 pictures below were extracted from video captured on-board test train Network Video Recorder (NVR):

Figure 3.12: Approaching Test Train as recorded on board and viewed from NVR (Network Video Recorder)
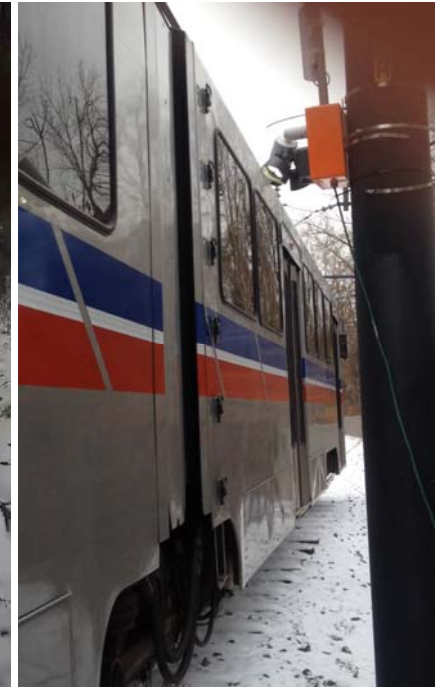
44

As the train approaches, the crossing light/alarm is activated from the vehicle given the preset "time to crossing" programmed to 20 seconds. At this point, the HRC package can then communicate to surface traffic controllers or gate mechanisms, or additional surface traffic lights/alarms via WiFi or Cellular networks; or relay logic interface.

The crossing alarm sequence is activated by any of the following (or any logical combination of these) inputs:
- Automatic activation via LRV based on LRV "distance to crossing" arrival threshold (expressed in feet or meters)
- Automatic activation via LRV based on LRV "time to crossing" arrival threshold (expressed in feet or meters)
- "Motion within crossing" per camera image detection versus a static image.
- "Occupancy within crossing" per camera image detection versus an empty crossing.
- Manual activation via Train Operator touch-screen button.
- Automatic activation via LRV after Cab alarm times out due to no braking command from Operator as measured by Master Controller position monitor.
- Automatic activation via LRV after Cab alarm times out due to no braking response of vehicle as measured by on-board accelerometer.

Figure 3.13a: Photo from inside Test Train   **Figure 3.13b and 3.13c:** Photos of approaching Test Train

45

Section 4:   Results and Conclusions of the Project

   In addition to the many results and conclusions that are described in this report, a summary of the target features demonstrated is summarized here.

4.1   Features / Impact Summary
During this project we set out to design, implement and demonstrate an interactive Highway-Rail Crossing (HRC) safety system with the following features to achieve the associated impacts:

	FEATURE	IMPACT
1	Active System – Alerts Operator	Improved alertness/response time of operator
2	Active System – Alerts Trespasser/worker	Improved alertness/response t of person at risk
3	Improved alertness/response time	Actively alerts operator & pedestrian/motorist
4	Active System – Applies Brakes	Actively alerts operator then applies brakes
5	Adaptive – works only when train approaches	Avoids false triggers
6	Comprehensive Record	Records events on the train and in the crossing.
7	Adaptable / Portable	Can be set-up in temporary work areas.

   The above **features 1, 2, 3, 4 and 5** are implemented and achieved by our system such it that can activate the crossing light/alarm from the vehicle given the preset "time to crossing"   programmed to 20 seconds.   At this point, the HRC package can then communicate to surface traffic controllers or gate mechanisms, or additional surface traffic lights/alarms via WiFi or Cellular networks; or relay logic interface.

The crossing alarm sequence is activated by any of the following (or any logical combination of these) inputs:
   a. Automatic activation via LRV based on LRV "distance to crossing" arrival threshold (expressed in feet or meters)
   b. Automatic activation via LRV based on LRV "time to crossing" arrival threshold (expressed in feet or meters)
   c.   "Motion within crossing" per camera image detection versus a static image.
   d. "Occupancy within crossing" per camera image detection versus an empty crossing.
   e. Manual activation via Train Operator touch-screen button.
   f. Automatic activation via LRV after Cab alarm times out due to no braking command from Operator as measured by Master Controller position monitor.
   g. Automatic activation via LRV after Cab alarm times out due to no braking response of vehicle as measured by on-board accelerometer.

Feature 6, a comprehensive record, is achieved via our on-board Data Logger/Event Recorder along with a NVR video record.

Feature 7, the HRC package being compact, low profile and under 10 lbs can easily be mounted on a battery / work area lighting cart for temporary work area applications.   Since it has on board GPS, it can report it location where ever it is set-up.

4.2   System / Component Cost Summary:

Approximate costs for the items / features are as follows.   Depending upon the application and features deployed (+ / - 25 %):

Highway – Rail Crossing (HRC) Package:

IP Camera (visible + IR)	~ $800.00
Integrated 5.0 GHz Antenna	~ $350.00
Power Supply (PoE devices)	~ $225.00
Crossing Comms Pack (WiFi + GPS + Cellular)	~ $2,000.00
Flood Lighting and Audible Alarm	~ $350.00
Ruggedized packaging (inc. mounts, band clamps)	~ $700.00
DIN Rails, Relays, Misc components	~ $100.00
Wiring harness, conduit etc.	~ $125.00
	~ $4,500.00

Base Carborne Package:

Rugged Touchscreen Monitor	~ $1,500.00
Integrated 5.0 GHz Antenna (Streaming video)	~ $450.00
Vehicle Comms Pack (WiFi + GPS + Cellular)	~ $2,000.00
Vehicle Shark-fin Antenna (WiFi + GPS + Cellular)	~ $120.00
Power Supply	~ $225.00
Network Video Recorder (NVR)	~ $450.00
Ruggedized packaging, custom mounts etc.	~ $450.00
Wiring harnesses, conduit etc.	~ $225.00
	~ $5,000.00

Carborne Package (optional):

IEEE 1482.1 Event Recorder / Data Logger (optional)	~ $5,000.00
Crash-Hardened Memory Module	~ $1,500.00
Accelerometer	~ $1,500.00
Vehicle Safety Platform (optional)	~ $6,000.00

Note: Installation and customization NRE not included.   Other base features and packages could be offered depending on the application.

4.3   **Prospective (and alternative)** Applications

Outlined here are some possible applications of our system and various features and technology.

4.3.1 Positive Train Control (PTC) / Positive Separation (PTS): Positive train control (PTC) is a system of functional requirements for monitoring and controlling train movements to provide increased safety by having the following characteristics:
   ➤ Train separation or collision avoidance
   ➤ Line speed enforcement
   ➤ Temporary speed restrictions
   ➤ Rail worker wayside safety

PTC / PTS is an enhanced overlay system that uses digital RF communications and computers onboard locomotives to automatically control train movement. PTS includes collision protection features and optional onboard display capabilities which enforce safe train operation.

Our GPS Track Map generation capability along with GPS technology on either or both ends of an LRV or even very long Freight train consists and tachometer signal to fill in train position when GPS drops out could constantly communicate its presence / position forward and behind the train and approaching train if similarly equipped could keep a positive safe separation distance away.

This could evolve into a "moving block" scheme wherein all trains can actively transmit a safe "block" distance around them based on their size, position and instantaneous speed. Obviously such a system would have prevented recently reported and dramatic de-railments in Spain and the most recent on at the Spuyten Duyvil station in the Bronx on Metro-North's Hudson Line. Our system has all of the components necessary to track location, store speed limits and enforce speed limits, including active downgrades due to dynamic conditions. While such systems exist, we believe the cost and flexibility of our system would permit a railroad or transit authority to perhaps deploy such technology ahead of when larger budgets may be made available.

Existing Trolley lines may benefit from this type of car-borne capability / system.

4.3.2   Advanced Warning for Railroad Delays (AWARD): Current AWARD technology uses acoustic sensors and radar speed guns to alert motorists of delays at HRCs due to train activity or blockage. An AWARD program in San Antonio, Texas in 1998 was undertaken where acoustic sensors and radar speed guns were placed upstream of three locations near the intersection of Woodlawn Avenue and the Union Pacific Railroad line parallel to Interstate 10 in San Antonio. The sensors detected the presence, length and speed of trains approaching the crossings. The duration(s) of blockage were calculated, and the predicted delays were then disseminated in three ways:
1. Variable message signs upstream to the crossing alerted drivers to take alternate routes or freeway exits to avoid the delay.
2. The TransGuide traffic management center included the delay information in up-to-the-minute link speeds distributed via the Internet, kiosks and in-vehicle displays.
3. Emergency service vehicles such as ambulances used the delay information to plan their routes in real-time.

Our system could perform similar functionality communicate with traffic management systems via cellular networks and provide real-time updates.

4.3.3 Second Train Coming (STC) Detection: A second train coming system uses railway sensors and a Changeable Message Sign (CMS—also referred to as Variable Message Signs) to warn drivers of the presence of a second train which is approaching the crossing soon after an initial train has cleared the crossing. After the crossing gates have been lowered, sensors in the track detect a second train coming and then activate the CMS. The CMS usually displays a STC warning such as "Danger: Second Train Approaching." The most common types of CMS use fiber optics, light-emitting diodes (LED), reflective disks, or a combination of these technologies.

The Maryland Mass Transit Administration (MMTA) enacted a second train coming project in1998 and 1999. MMTA used an LED matrix to display the warning.   Modified signal circuits controlled the STC sign. Video-taped observation indicated that risky driver behavior decreased by 36% after the system was installed at this location. The Los Angeles County Metropolitan Transportation Authority has also tested and installed a STC sign on its light rail transit line in 2001.

4.3.4 Four Quadrant Gate System with Obstacle Detection: Four quadrant gates block both sides of the highway at each side of an HRC so that waiting vehicles cannot cross the tracks. If an obstacle or malfunction of the gate system were detected that would disable it from properly restricting the traffic, a warning signal could be sent to an approaching train and it could slow it approach to the HRC.

4.3.5 Intelligent Grade Crossing: Intelligent Grade Crossings are locations that have equipment with the following characteristics, all of which consist of features our system could perform:

Constant Warning Time: The Intelligent Grade Crossing provided a constant (typically 30-second) warning time to drivers, regardless of the train's speed or type, by activating both the crossings active warning signals as well as nearby variable message signs.

Stalled Automobile Detection: A combination of conventional loop detectors and high-tech video-based sensors detected if a vehicle was stalled on the tracks, if traffic backed up onto the tracks, or if a vehicle was unable to exit the crossing area. The Intelligent Grade Crossing Systems could turn the traffic signal lights to green, allowing vehicles to exit the crossing, thus clearing the queue from the crossing. If the crossing was blocked, a signal was sent to the locomotive engineer in time to stop the train before it reached the crossing or slow the train down as much as possible.   Such a system could stop or slow the train—equipped with PTC technology—automatically, if necessary.

Emergency Vehicle Priority: If an equipped emergency vehicle needed to cross the tracks, it could send a message via wireless communications to the Intelligent Grade Crossing. The ICG then caused the train to safely brake prior to the crossing, if the train's speed and distance allowed. Otherwise, the request was denied until the train had passed.

Minimize Gate Down Times: The Intelligent Grade Crossing minimizes gate down times, making operation of the signal system more reliable to drivers, who otherwise might be tempted to "game" the system if they are uncertain it is working or if a train is really imminent in arriving.

Variable Message Signs: The Intelligent Grade Crossing allowed nearby variable message signs to display messages that informed drivers of current conditions at the crossing. Messages displayed included "Train Approaching", "Crossing Delay", "Exit Lane Blocked" and "Train in Station".

Section 5:   Investigator Profile

The Principal Investigator is Mr. Carl E. Conti.   His full contact information is as follows:

SIL4 Systems Inc.
Mr. Carl E. Conti, President & CEO
669 Washington Road
Pittsburgh, PA 15228

Email: cconti@sil4systems.com
Phone: 1.412.343.1180
FAX: 1.412.343.1158

APPENDIX A: Highway-Rail Crossing Safety System Survey

Highway Crossing Safety System - Questionnaire

*SIL4 Systems is engaged in a **Transportation Research Board (TRB)** program to develop enhanced Highway Rail Crossing Safety Strategies and System. It would be of great help to this program if you were to contribute your expertise and take 10 minutes and fill out the following questionnaire.*

SIL4 Systems, Inc. Highway Rail Crossing Safety Survey	
Respondent Type: Anonymous	**Custom Data 1:**
Name:	**Custom Data 2:**
Email address:	**Custom Data 3:**
IP address: 204.126.146.202	**Survey Started:** 11/14/2012, 10:14 PM GMT
	Survey Ended: 11/14/2012, 10:14 PM GMT

1. How many Highway – Rail Crossings does your Transit Authority Operate?
50 - 100

2. How many Highway – Rail Crossings incidents (pedestrian or Motorist) do you experience per year on average:
10 or less

3. What type of Highway – Rail Crossings Signaling/Signage do you currently have at most Crossings:
Lights and Gating

4. Would you be interested in providing feedback on a Highway - Rail Crossings Safety Enhancement System?
Yes

5. If yes, please continue:

Please rate from 1 to 6 each of the following as likely causes of incidents (1 = most likely; 6 = least likely)
Pedestrian/Motorist risky/ill-advised behavior: 6
Pedestrian/Motorist confusion: 6
Inadequate/Confusing signals or queuing system: 6
Inadequate public awareness: 6
Inadequate late-stage warning: 6
Other: (no answer)

6. If you chose "other", please describe:
(no answer)

7. Please rate from 1 to 6 each of the following Highway Rail Crossing Features that would likely IMPROVE Safety (1 = Most likely to improve Safety; 6 = Least likely):

Increase Pedestrian/Motorist awareness: 6

Lessen Pedestrian/Motorist confusion at crossings: 6

Clearer signals or queuing system: 6

Increase public awareness of crossing dangers and safe-guards: 6

Increase late-stage warning: 6

Other: (no answer)

8. If you chose "other", please describe:

(no answer)

9. Do you think a conspicuous camera in the crossing would improve and make more cautious Pedestrian/Motorist behavior?

Somewhat likely to improve caution

10. Your Name (optional)

xxx xxx

11. Your Email Address (optional)

xxx@rideuta.com

12. Is there a person in your organization who's input you think would be valuable to this effort?

Their name (optional)

(no answer)

13. Their Email Address (optional)

(no answer)

14. Comments / Feedback

More specific pedestrian treatments , signs for pedestrians and traffic need to be explained. in more detail/descriptions.