1. Report No. CA13-2062E	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Pager Performance for the Western Transportation Institute's augmented Speed Enforcement Project	5. Report Date 07-06-2013
	6. Performing Organization Code

7. Author(s) Larry Hayden	8. Performing Organization Report No.

9. Performing Organization Name And Address Western Transportation Institute, College of Engineering Montana State University, Bozeman, Montana	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. 65A0355

12. Sponsoring Agency Name and Address California Department of Transportation Division of Research, Innovation and System Information (MS-83) P. O. Box 94287 3Sacramento, CA 94273-0001	13. Type of Report and Period Covered Final Report From 12/2009 – 06/2013
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The purpose of the augmented Speed Enforcement (aSE) project was to detect and warn speeding vehicles in a work zone and provide warnings to work zone workers. The system developed by Montana State University consists of 28 orange traffic drums (called smart drums or sDrums) that were positioned adjacent to the orange cones marking the work zone lane closure. When the system detects a speeding vehicle approaching, it synchronously flashes the orange lights on top of the drums, warning the driver to slow down and the workers of a speeding vehicle. If the vehicle speed is above a set trigger speed, the system activates a pager system that warns the workers of the speeding vehicle. The sDrum system used a Long Range Systems pager system which is the focus of this report. Basic range measurements were performed for the transmitter and a repeater since there is no published range. The transmitter's range was measured over 600 feet and the repeater range was approximately the same. The transmitter to repeater range measured over 1700 feet. Transmitter and repeater power consumption were also measured. This report contains the full results of the pager system tests performed.

17. Key Words aSE, sDRUM, sCONE, Long Range Systems	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report) none	20. Security Classif. (of this page) none	21. No. of Pages 35	22. Price N/A

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

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Pager System Performance for the augmented Speed Enforcement Project

by

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A report prepared for the

U.S. Department of Transportation

Research and Innovative Technology Administration

Washington, DC

Final Report

March 5, 2014

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EXECUTIVE SUMMARY

The purpose of this project, augmented Speed Enforcement (aSE), was to detect and warn speeding vehicles in a work zone as well as providing warnings to work zone workers. The project consisted of two systems, one provided by California PATH at UC Berkeley and the other developed by the Western Transportation Institute (WTI) of Montana State University. Either can be deployed independently or they can be deployed together.

The purpose of the WTI project was to design, assemble, and real world test a deployable smart drum system for rural area work zones. The original concept was to develop a warning system for work zones that would detect vehicle speeds and track a speeding vehicle using warning lights mounted on traffic cones. The warning lights would warn the work zone workers and the speeding driver. Due to the project schedule being compressed and the difficulty of the task, the tracking requirement was postponed; the warning lights were designed to simply flash synchronously upon detection of a speeding vehicle.

With the assistance of the California Department of Transportation (Caltrans), the pilot system was deployed for four weeks near Los Banos, CA to evaluate the effectiveness and deployability of the sDrum system.

The sDrum system used a pager system to warn maintenance works and Maintenance Zone Enhanced Enforcement Project (MAZEEP) California Highway Patrol Officer of excessively speeding vehicles which is the focus of this report.

A Long Range Systems (LRS) Pager System was chosen for the sDrum system. The transmitter has a RS-232 serial communication port for configuration and the pager is a simple non-alpha numeric pager with a strong vibration alert. It was reasoned an audio alert in a noisy construction environment would be ineffective so a strong vibration alert was a priority for the pager.

Initial testing showed the system had a range of approximately 500 feet. Several ways to improve the range were explored including antenna ground planes, tuned pagers and using a repeater.

Range testing showed that tuned pagers have approximately twice the range of an unturned pager, a ground plane improves range, and if tuned pagers are used a repeater can extend the range to over 3000 feet.

1. BACKGROUND

Speeding is a primary factor contributing to major injury and fatality crashes in rural area highway work zones. Automated Speed Enforcement (ASE) detects speed violators and automatically processes speeding citations, but there can be legal barriers for some jurisdictions to implement ASE. Augmented Speed Enforcement (aSE) which is based on similar technologies utilizes the information about detected violators to notify an onsite California Highway Patrol (CHP) Officer to manually identify and stop the speeder. The development of aSE was conducted with funding from the Research and Innovative Technology Administration (RITA) in the United States Department of Transportation.

As shown in Figure 1, the aSE system consists of two systems developed by two research teams with both systems operating in the same work zone. One system developed by California PATH at UC Berkeley has a camera with built in radar to detect and photograph the license plates of speeding vehicles. Upon detecting a speeding vehicle the vehicle's license number and speed are recorded and displayed on a changeable message sign. The same data is transmitted to a CHP Officer located in the work zone. The CHP Officer will use his radar system to verify the vehicle speed and determine whether or not to issue a citation.
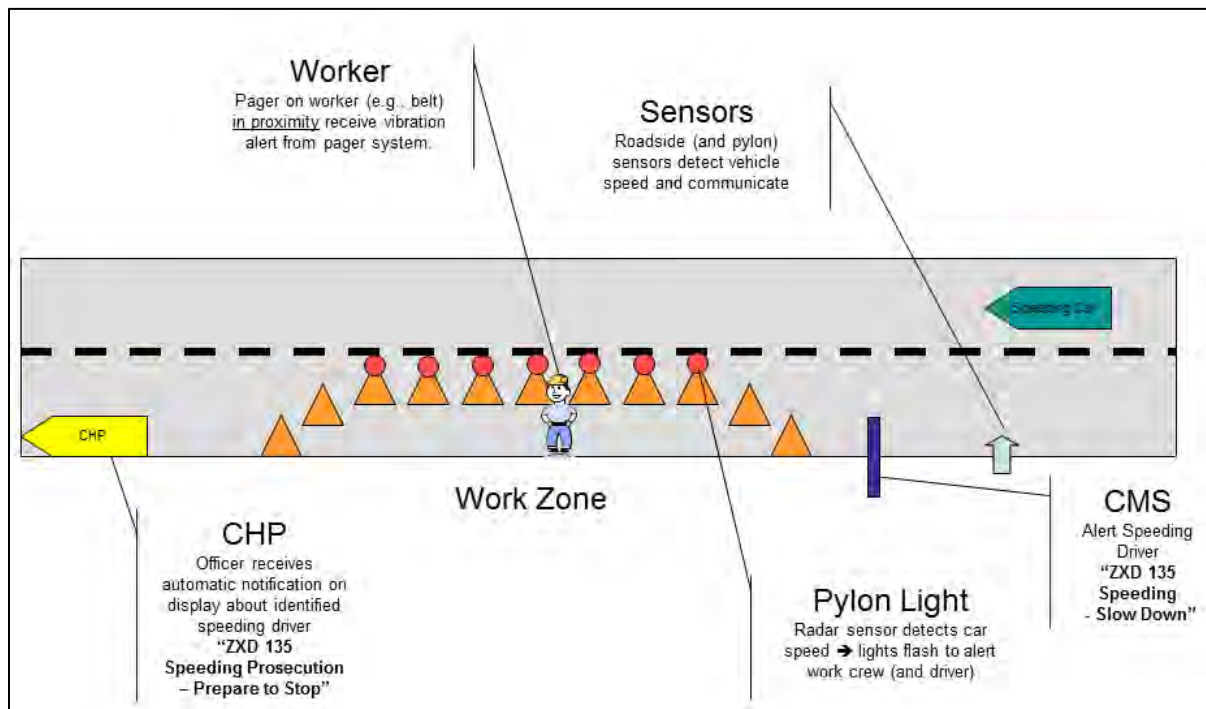
Figure 1: aSE System Diagram

The second system was developed by WTI. It consists of 28 orange traffic drums that are positioned adjacent to the orange cones marking the work zone lane closure. When the system detects a speeding vehicle approaching, it synchronously flashes the orange lights on top of the drums, warning the driver to slow down and the workers of a speeding vehicle. Also, if the vehicle speed is above a pager set speed, the system triggers a pager system that warns the workers of the speeding vehicle. The WTI system was dubbed the smart drum (sDrum) system.

The sDrum system architecture is shown in Figure 2. The master drum is the control center of the system and receives vehicle speeds from its internal radar and flashes the lights and triggers the pagers depending on the vehicles speed and the controller's configuration. The master drum communicates with slave, logger, and pager drums through an XBee (proprietary ZigBee) mesh radio network. Logger drums solely log vehicle speeds although they contain the same components as the master drum. The repeater drum repeats transmissions received from the pager transmitter, extending the range of the pager system.
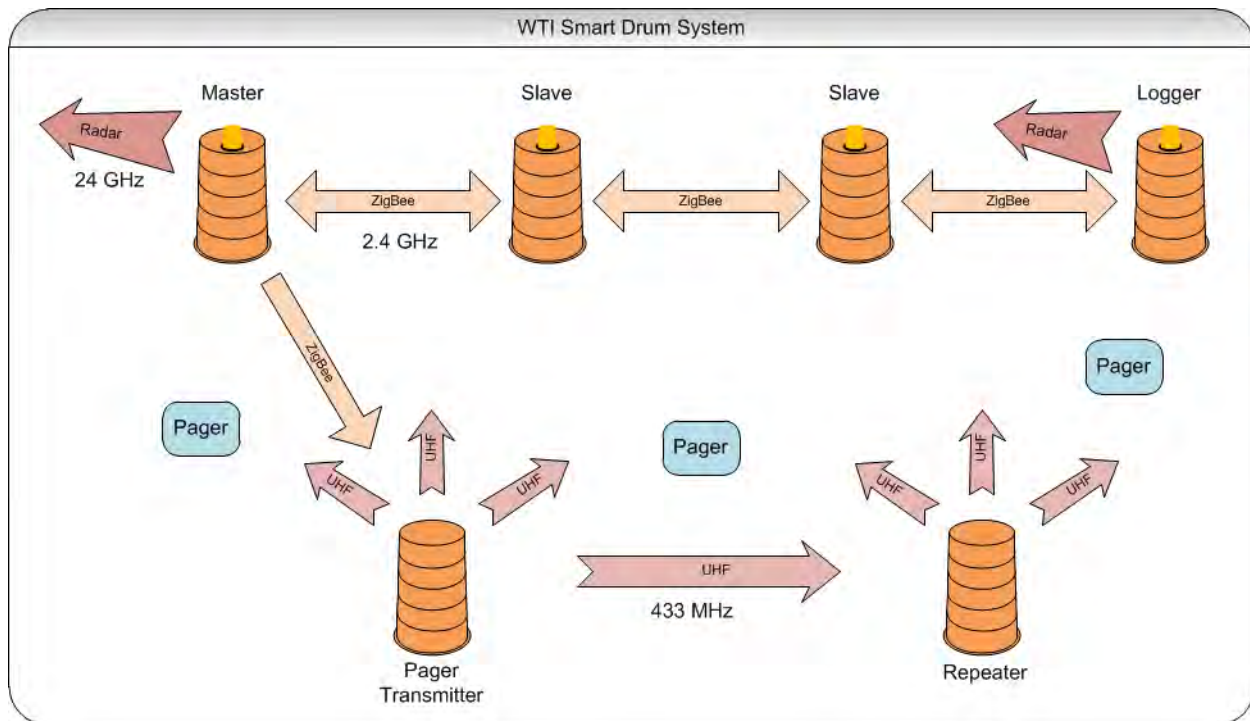
Figure 2: sDrum System Architecture

The full sDrum system includes one master, 24 slaves, three loggers, one pager and optionally one repeater drum. The master is at the beginning of the line and a logger is at the end of the line. The other two logger drums are equally spaced between the master and the last logger drum. Eight slaves are deployed between the master and logger drums and between the other logger drums. The pager and repeater drums are deployed on the shoulder of the roadway, positioned to provide the best work zone coverage.

2. INTRODUCTION

This report focuses on the Long Range Systems (LRS) Pager System chosen for the sDrum system. The transmitter has a RS-232 serial communication port for configuration and the pager is a simple non-alpha numeric pager with a strong vibration alert. It was reasoned an audio alert in a noisy construction environment would be ineffective so a strong vibration alert was a priority for the pager. A repeater drum was built and tested after deployment to find a solution for improving the pagers range of approximately 500 feet.

The LRS pager system is typically used in the restaurant industry and was chosen for the WTI system as a reasonable option for system development.

This document details WTI's LRS pager and repeater testing including post deployment testing at our Transcend laboratory. Note most of this material is included in WTI's aSE Final Report.

3. DESIGN/DEVELOPMENT

A strong vibration alert was a priority for the pager as it was reasoned an audio alert in a noisy construction environment would be ineffective.

3.1. Pager System

The LRS pager system is typically used in the restaurant industry and was chosen for the WTI system as a reasonable option for system development. A repeater is used to extend the range of the transmitter.

3.1.1. Transmitter

The Long Range Systems (LRS) Pager System transmitter has an RS-232 serial communication port shown in Figure 3 to the left of the antenna. Four parameters: restaurant ID, repeat delay, power setting and frequency, can be set through the RS-232 serial port with a terminal emulator. None of the default parameters were changed in the WTI system.

Figure 3: LRS Pager Transmitter - LRS Image

The pager transmitter required a 10V ac power supply and LRS included a 110V ac to 10V ac power supply with the unit. To avoid several voltage conversions, a 12V dc to 10V ac inverter manufacturer was researched. That being unsuccessful and with the tight schedule not allowing enough time for a custom design, a standard 12V dc to 110V ac inverter was used with the LRS power supply.

Much later in the pilot design a backup transmitter was purchased that came with a 12V dc power supply, although the transmitter was still labeled as 10V ac input. After exchanging several emails with LRS it was learned that all of the transmitters could accept 12V dc directly. This eliminated two components saving approximately 290 mA of current drain, thus extending battery run time by several days, and increasing the reliability of the system.

3.1.2. Pager

The pager is a simple non-alpha numeric pager with a strong vibration alert. See Figure 4. One to four LEDs can be flashed with audible beeps and/or vibrations. The pagers can be wirelessly programmed with individual pager numbers but for our purposes all pagers were programmed as number 1. The pagers were set to flash one LED and vibrate three times per page during

deployment, although it had been inadvertently reset and had to be reprogrammed during deployment.

Figure 4: LRS Service Pager - LRS Image

Note the pagers do not have an on/off switch; they are "on" when taken out of the charger, shown in Figure 5, so the pagers must be stored in the charger to avoid dead batteries. When not being utilized and out of the charger, the pagers remain operational for approximately one day although the manufacturer claims approximately 72 hours. The state of battery charge cannot be checked externally but the pager blinks all four LEDs when the battery is about to die. The batteries are not user replaceable.

Figure 5: LRS Pager Charger - LRS Image

3.1.3.　　Repeater

The repeater appears identical to the transmitter except it does not have a serial port. See Figure 6. It is used to extend the range of the pager system; more than one repeater may be used. Only 12v dc power is required for operation. Operation is simple; connect power.

Figure 6: LRS Repeater - LRS Image

3.2.   Software Suite

The sDrum system requires two types of software:

- Linux control software that operates the system and runs on the Moxa controller,
- Management software for system configuration and testing which runs on a Windows laptop/desktop computer.

The software suite was programmed by WTI's systems group.

3.2.1.   Control Software

The control software is installed on the Moxa computers located in the master and logger drums. It controls data collection, paging and light states.

3.2.2.   Management Software

The aSE Management software is a Graphical User Interface for administrating the various functions of the sDrum system. The software can be used to connect to any master or logger although only set time, radar device and signal device can be accessed on a logger controller.

The aSE Management software opening screen is shown in Figure 7.
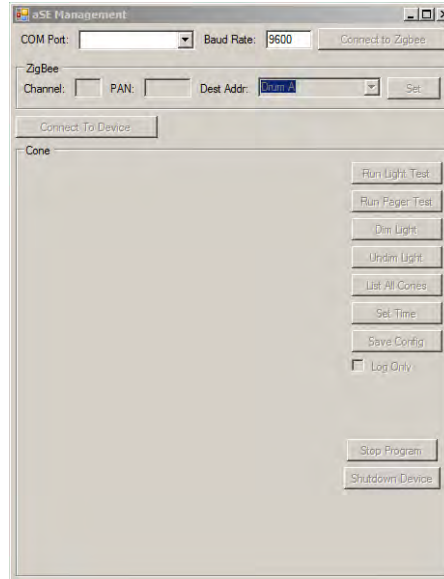
Figure 7: aSE Management Opening Screen – WTI Image

The appropriate COM port must be selected and the 9600 baud rate verified. The "Connect to Zigbee" button initializes the XStick, which is an XBee radio in a USB (universal serial bus) stick form for use with a laptop. Note a more powerful XBee radio in a USB dongle type form is available. Also the XBee radio is a proprietary implementation of a ZigBee radio.

When the XStick is connected to the management software the screen will look like Figure 8.

Figure 8: XStick Connected – WTI Image

By default, the Channel and PAN are set to "C" and "7FFF" respectively. Note all of the radios in the system must be set to the same Channel and PAN to communicate.

The "Dest Addr" is the address of the ZigBee radio for the drum the XStick is connecting to. The first time the aSE Administration software is run the 16 digit alpha-numeric Dest Addr must be entered. "Set" saves the communication settings. The XStick remembers the address from

the previous session; however, to change the settings of another drum the new address must be entered.

The "Connect to Device" button initializes communication with the drum and will populate the interface with the drum's settings. See Figure 9.
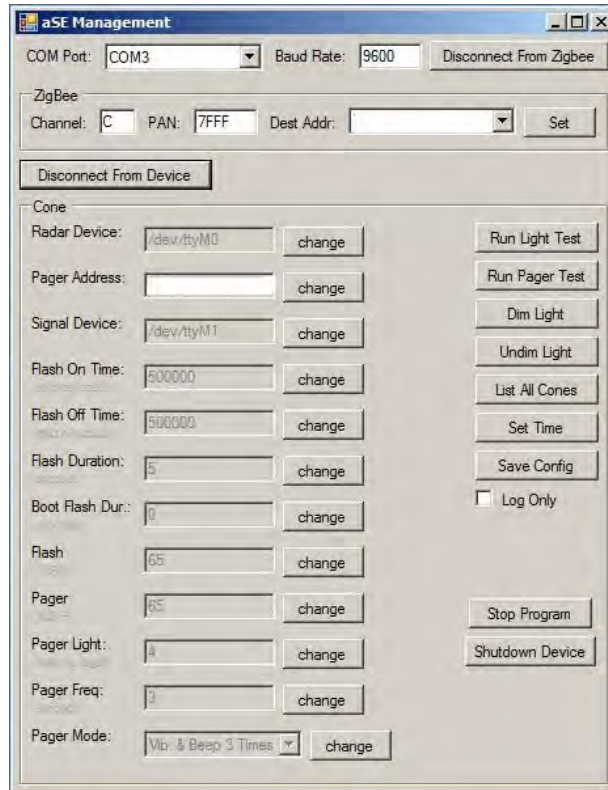
Figure 9: Connected to sDrum Screen – WTI Image

At this point, communication with the drum has been established and the functions of the drum can be configured. The following descriptions refer to Figure 9.

Adjustable Parameters:

- Radar Device - identifies the Moxa serial port the software expects the radar to be connected to. If by chance the RJ-45 connections for the radar and the light become switched, this setting enables the ports in the Moxa software to be changed, restoring proper function.
- Pager Address - the radio address of the pager drum's ZigBee radio.
- Signal Device - the same function as the "Radar Device" function, described above.
- Flash On Time - the time that the light is illuminated, in microseconds. Currently set at 500000μs, or 0.5s.
- Flash Off Time - the time that the light is not illuminated, in microseconds. Currently set at 500000μs, or 0.5s.
- Flash Duration - the length of time that the lights flash after the radar confirms a speed above the trigger speed. It is currently set for 5 seconds.
- Boot Flash Duration - length of time in seconds that the light flash routine runs at power on. This is used to synchronize the radios upon initialization. Currently set at 0 seconds.

- Flash - speed in mph that the Moxa needs to receive from the radar for it to begin the light flashing routine. This is currently set at 65 mph.
- Pager - threshold speed in mph that the Moxa needs to receive from the radar for it to send a command to the pager transmitter. This is currently set to 65 mph.
- Pager Light - sets the number of pager lights to illuminate. This is set at 4.
- Pager Freq - tells the pager transmitter how long to delay between pages. Currently set to 3 seconds.
- Pager Mode - changes the options of how the pager behaves when it receives a page from the pager transmitter. Currently the pager will vibrate and beep 3 times.

Button Functions:

- Run Light Test - sends a command to the master drum to turn the lights on and off for all drums in the master's network. This routine runs for the time specified by Flash Duration. This is useful for verifying that all of the drums in the network are functioning normally.
- Run Pager Test - sends a command to the master drum to transmit a single page. This test is useful for verifying pager operation.
- Dim Light - reduces the light's output by approximately 50% enabling the system to be used at night.
- Undim Light - reverses the Dim Light function and returns the light to 100% brightness.
- List All Cones - Opens a popup screen which lists the radio address of all drums connected to the master's network; initially the popup will be blank but when "Find Additional Cones" button is clicked, the address and ID of the connected drums will populate. In addition to the address, there is RSSI (Received Signal Strength Indicator) which is a snapshot of the connection quality of the last hop to the address specified. The "Done" button closes the popup window shown in Figure 10.
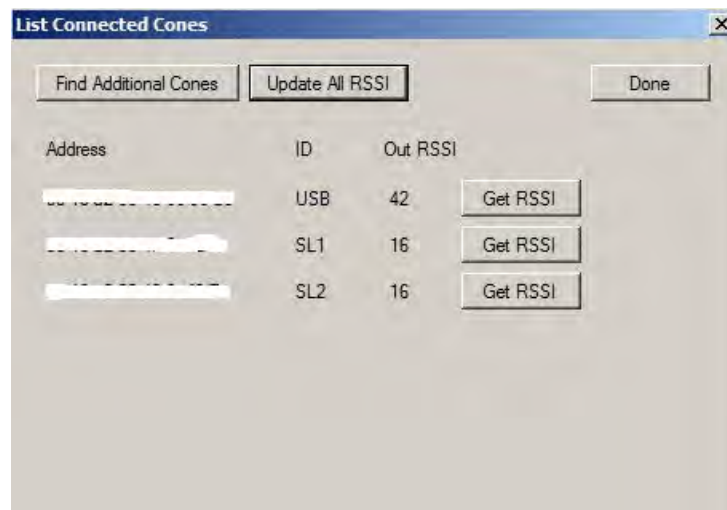

Figure 10: List Connected Cones Screen – WTI Image

Note: The XStick's ID is "USB" and since there are two other drums currently in the network, there are three addresses. The drum the XStick is "connected to" does not show up because it is doing the interrogation. The listed drums are connected TO the drum being configured.

- Set Time - synchronizes the Moxa clock in the master with the clock of the laptop or desktop running the aSE Management software.
- Save Config - saves all of the changes made during a session in the aSE Management program to the memory in the master drum. If the Save Config button is not pushed, any changes made will be lost when the master is turned off; configuration will revert back to the last saved configuration upon restart.
- Log Only - ceases sending light flash commands to the drums in the network; it will continue to record the speeds sent by the radar. It is useful for operating the system incognito.
- Stop Program - stops the software program running on the Moxa. The master will not send light flashing commands or pager commands and will not record the speeds measured by the radar.
- Shutdown Device - turns the master's Moxa computer off. No further communication with the master drum is possible until the drum's power switch is turned off, then on again to reboot the system.

The "Disconnect from Device" severs communications with the drum; and "Disconnect from ZigBee" shuts off the XStick.

3.2.3.   Pager Trigger Application

The pager trigger application was written to enable one person to test pager range. A screen shot of the application's graphical user interface is shown in Figure 11. The application runs on a laptop and uses an XBee radio to communication with the pager drum radio; the COM Port is the port the XBee USB radio is attached to.

To operate, simply set the page interval and click the Start button. It will continue to send pages at the set interval until the Stop button is clicked.
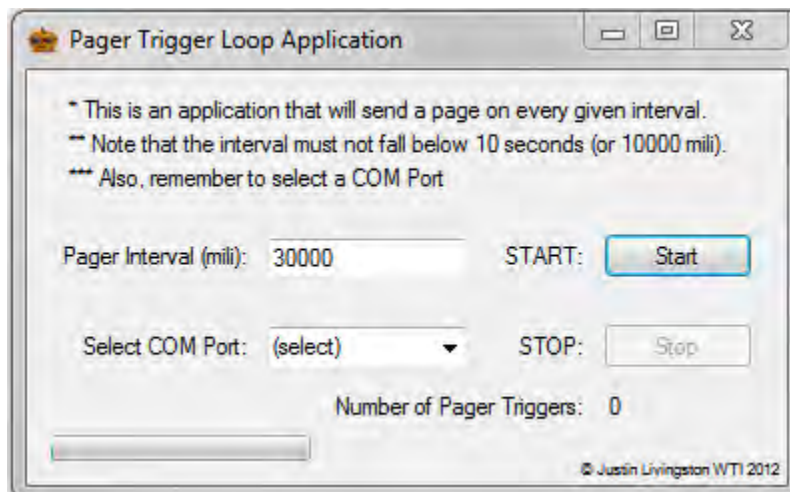
Figure 11: Pager Trigger Application _ WTI Image

4. TEST

Pager system range measurements were performed in April and June at WTI. Power usage was also measured for both the pager and repeater drums. In August 2012, to corroborate range results measured near WTI and to see if the retaining wall or chain-link fence had a measureable effect on the results, the pager system was taken along to WTIs Transcend lab for further pager range tests. The pager trigger application was written to expedite pager testing at Transcend.

4.1.   Range Measurements

Both pager and repeater range were measured showing tuned pagers improved range significantly.

4.1.1.   Range Test Setup

- Initial Range Test

The LRS pager system was tested using the pager drum, a master cone, and a laptop computer running the aSE Management software. See Figure 12. The aSE Management software only controls the Moxa controller so the Moxa had to initiate the pages. The laptop computer communicated with the Moxa controller through the Digi USB dongle or XStick and the master cone's radio.

Figure 12: Pager Test Setup - WTI Image

The hand truck test fixture was used to hold the pagers with the pagers facing rearward. See Figure 13. The pagers were clipped to cardboard strips attached to the hand truck to keep the pagers consistently oriented.

Figure 13: Pager Range Test Fixture - WTI Photo

After returning from the first two weeks of deployment, ways to improve pager range were discussed. A ground plane was known by one researcher to typically improve low angle antenna patterns, improving the range, so ground planes were investigated.

- Ground Plane Test

Figure 14 shows the "no ground plane" test fixture which uses a piece of cardboard to hold the antenna in the frame. This simulates the current pager drum's installation. Figure 15 shows the small ground plane which is a small aluminum plate approximately 6 inches in diameter. The plate is setting on the piece of cardboard to isolate the plate from the frame. Figure 16 shows the large ground plane which is a 2 foot square aluminum sheet. It is also setting on the piece of cardboard.

Pagers #6, #7 and #8 were used with the hand truck and the laptop was running the aSE Management software.

Figure 14: No Ground Plane – WTI Image

Figure 15: Small Ground Plane – WTI Image

Figure 16: Large Ground Plane - WTI Image

When discussing the pager range issue with LRS, it was suggested three pagers be returned to LRS for tuning. Since there was not enough time to get the pagers tuned before returning to Los Banos, four tuned pagers were purchased for use during WTIs June deployment.

- Tuned Pager Test

The new tuned pagers were range tested along with three of the other pagers before returning to Los Banos. They were arranged on the hand truck as shown in Figure 17. Note the pagers were placed in front of the metal handles; this reduced the possibility of the handles affecting the results. The pager drum was placed across the street to reduce the possibility of the retaining wall or the chain link fence affecting the results.

Figure 17: Tuned Pager Range Test Fixture – WTI Image

- Repeater Range Test

The pager transmitter was placed at the end of the runway and powered up. See Figure 18. A laptop with an XStick installed and running the pager trigger software was place close by. The repeater and four pagers were placed on the hand truck.

Figure 18: Transcend Lab Repeater Test - WTI Image

4.1.2.   Range Test Procedure

- Initial Range Test

The hand truck with pagers was advanced in 50 or 100 feet increments, depending on the test, and the individual pager results recorded. Testing required two people, one operating the hand truck and documenting the results and the other operating the laptop software. Pages were initiated manually using the aSE Management software.

- Ground Plane Test

Ground plane testing started near Kagy Boulevard with the pager transmitter placed near the intersection of Kagy and 11th Avenue. See Figure 19. Pagers #6, #7, and #8 were used in the same hand truck setup as the previous tests with the beep activated for easier recognition. Pages were initiated manually using the aSE Management software.

Figure 19: Ground Plane Test Site - Google Earth Image

- Tuned Pager Test

The hand truck with pagers was advanced in 50 or 100 feet increments, depending on the test, and the individual pager results recorded. Testing required two people, one operating the hand truck and documenting the results and the other operating the laptop software. Pages were initiated manually using the aSE Management software.

- Repeater Range Test

Pages were initiated using the pager trigger software. The hand truck with pagers and repeater was walked down the runway, away from the pager transmitter, until the pagers stopped beeping. The repeater was removed from the hand truck and powered up. After confirming the pagers were beeping again the hand truck was walked further down the runway until the pagers stopped beeping. The distance between the hand truck and repeater drum is the pager range from the repeater.

The repeater drum was returned to the hand truck and it continued down the runway until the pagers stopped beeping again. Measuring the distance between the hand truck and pager transmitter provides the repeater to pager transmitter range.

4.1.3.   Range Test Results

- Initial Range Test

Range test results for pagers numbered 1 through 12 are shown in Table 1. The table indicates a reliable range of about 500 to 600 feet, which is marginal for the WTI application.

Table 1: Initial Pager Range Results

Range (ft.)	Pager # 1	2	3	4	5	6	7	8	9	10	11	12
450		x		x	L	x	L	x	x	x	x	x
550	x	x		x	x	x	x	x	x	x	x	x
650	x	x	x	x	x	x	x		x		x	x
750	x	x		x	x	x	x	x	x		x	x
800		x		x	x		x		x			x
850				x	x			x				
950												
1050												
1150												
1250												
1350												
1450												
1550					x				x			
1600					x				x			

Legend:
x	Page
(red)	No Page
L	Late Page
(white)	Not Tested

- Ground Plane Test

Table 2 compares the range with and without a ground plane. Note that range significantly improves with a large ground plane but even a small ground plane makes a noticeable improvement.

Table 2: Ground Plane Test Results

Range (ft)	No Plane Pager #				6" Plane Pager #				24" Plane Pager #			Comments
	6	7	8		6	7	8		6	7	8	
100	x	x	x									
200	x	x	x									
300	x	x	x		x	x	x					
350					x	x	x					
400	x	x	x		x	x	x		x	x	x	
450					x	x	x		x	x	x	
500	x	x	■		x	x	x		x	x	x	Chain Link Fence Begins
550	x	x	x		x	x	x		x	x	x	
600	x	x	x		x	x	x		x	x	x	
650	x	x	■		x	x	x		x	x	x	
700	■	x	■		■	x	■		x	x	x	Concrete Retaining Wall Begins
750	x	x	■		x	x	■		x	x	■	
800	■	■	■		■	x	x		x	x	x	
850	x	x	■		x	x	x		x	x	x	
900	x	x	■		x	x	x		x	x	x	
950	x	x	x		x	x	x		x	x	x	
1000	■	x	■		x	x	x		x	x	x	
1050	■	x	■		x	x	■		x	x	x	
1100	x	■	■		x	■	■		x	x	■	
1150	■	■	■		■	x	■		x	x	■	
1200	■	■	■		■	x	■		x	x	■	End of Distance Test

x Page   ■ No Page

Some observations by the tester:

1. No ground plane - There were three distinct beeps as each pager received the page.
2. 6" ground plane - All beeps were essentially simultaneous, until the 650' mark, when they started to become distinct from each other.
3. 24" ground plane - All beeps were simultaneous until the 1100' mark.

- Tuned Pager Test

The "tuned" pager range test results are shown combined in Table 3. The pager order on the hand truck was, from left to right, 6, 7, 8, 13, 14, 15, and 16 in the left side table and 16, 15, 14, 13, 8, 7, and 6 in the right side table. The pager order was reversed in the second test to check whether the position on the hand truck influenced the results. As the tables show, there was significant

performance change for some pagers but more testing would be needed to identify the exact cause.

Note that the tuned pagers 13, 14, and 15 performed much better than the un-tuned pagers although pager 16 appears to have some issue with its first position. More testing would be needed to identify the cause.

Table 3: Pager Range Comparisons

Range (ft.)	Pager # 6	7	8	13	14	15	16	Range (ft.)	Pager # 6	7	8	13	14	15	16
100	x	x	x	x	x	x	x	100							
200	x	x		x	x	x	x	200	x	x	x	x	x	x	x
250	x			x	x	x	x	250	x	x	x	x	x	x	x
300	x	x	x	x	x	x	x	300		x	x	x	x	x	x
350	x	x	x	x	x	x	x	350	x	x	x	x	x	x	x
400	x	x	x	x	x	x	x	400	x	x	x	x	x	x	x
450	x	x	x	x	x	x	x	450	x	x	x	x	x	x	x
500	x	x	x	x	x	x	x	500	x	x	x	x	x	x	x
550	x	x	x	x	x	x	x	550		x		x	x	x	x
600	x	x	x	x	x	x		600				x	x	x	x
650		x	x	x	x	x		650				x	x	x	x
700	x	x	x	x	x	x	x	700	x	x	x	x	x	x	x
750	x	x	x	x	x	x	x	750	x	x	x	x	x	x	x
800	x	x	x	x	x	x		800	x	x		x	x	x	x
850	x	x	x	x	x	x		850	x	x		x	x	x	x
900	x	x	x	x	x	x		900	x	x		x	x	x	x
950	x	x	x	x	x	x		950	x	x		x	x	x	x
1000	x	x	x	x	x	x		1000	x	x		x	x	x	x
1050		x	x	x	x	x		1050	x	x		x	x	x	x
1100				x	x	x		1100	x	x		x	x	x	x
1150	x	x	x	x	x	x		1150	x	x		x	x	x	x
1200		x	x	x	x	x	x	1200				x	x	x	x
1250		x	x	x	x	x	x	1250				x	x	x	x
1300				x	x	x		1300				x	x	x	x
1350				x	x	x	x	1350							

Legend: yellow **x** = Page; red = No Page

Since the tuned pagers were still performing well at 1300+ feet in the previous range tests, the test was repeated the next day, extending the range to 2200 feet, where most of the pagers failed. See Table 4. Note pager order was again 16, 15, 14, 13, 8, 7, and 6, left to right.

Table 4: Pager Range Results

Range (ft.)	6	7	8	13	14	15	16
500	X	X	X	X	X	X	X
600	X			X	X	X	X
700	X	X		X	X	X	X
800	X	X		X	X	X	X
900				X	X	X	X
1000	X			X	X	X	X
1100	X	X		X	X	X	X
1200	X			X	X	X	X
1300	X			X	X	X	X
1400	X	X		X	X	X	X
1500	X			X	X	X	X
1600				X	X	X	
1700	X	X		X	X	X	X
1800	X	X			X		X
1900					X	X	
2000						X	
2100				X	X	X	
2200						X	

Legend: X = Page; (red) = No Page

Note when measuring pager range from the repeater, when the pagers were between the pager transmitter and the repeater, they did not beep in unison, however they all did beep. The pagers beeped in unison prior to switching the repeater on, and when past the repeater.

- Repeater Range Test

Un-tuned pager range from the repeater was over 600 feet and repeater to pager transmitter range was over 1700 feet.

4.2. Power Usage

Power usage can be calculated by measuring the current and multiplying it times the voltage. Since in this case battery voltage is basically a constant, current is used to compare power consumption.

4.2.1. Power Test Setup

A Medusa Research Inc. Power Analyzer Pro test module was connected in series with the power supply and to a laptop with a USB cable. See Figure 20. A second laptop running the administration software's "Run Pager Test" or the master drum's speed triggered page was used for the test.
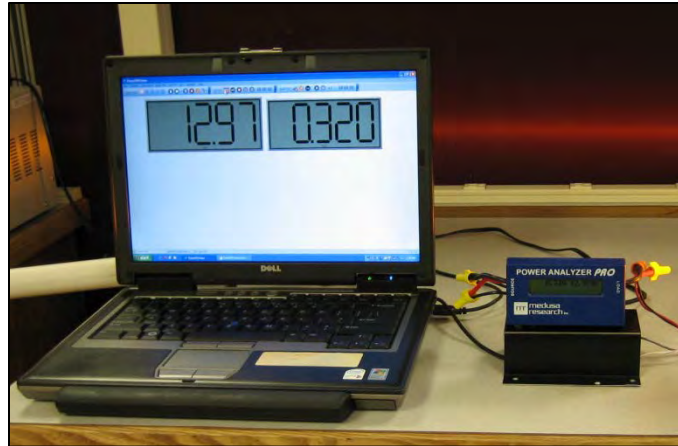
Figure 20: Power Test Setup – WTI Photo

4.2.2.   Power Test Procedure

The laptop was used to run the "Run Pager Test" three times then the master drum was used to trigger a page twice. The pager transmitter was set to page once for the laptop controlled page but twice for the master drum controlled page. The pages were initiated multiple times to verify consistency. The laptop running the Medusa Research's ProView software logged voltage and current to a file.

4.2.1.   Power Usage Results

Both the pager drum and repeater drum were tested for power usage with the repeater using nearly three times the power of the pager.

4.2.1.1.   Pager Power

The logged current data was plotted for comparison, see Figure 21. As expected there is little difference in current draw between a laptop controlled page and a master drum controlled page.

The pager drum has the three current states shown in Figure 21:

- Initial power on,
- Page and,
- Standby.

When the pager drum's power is switched "on" the pager transmitter is energized, drawing approximately 70mA. When the transmitter is commanded to page, the current jumps to over 500mA for a few seconds, then settles back to 90mA waiting for the next page command.
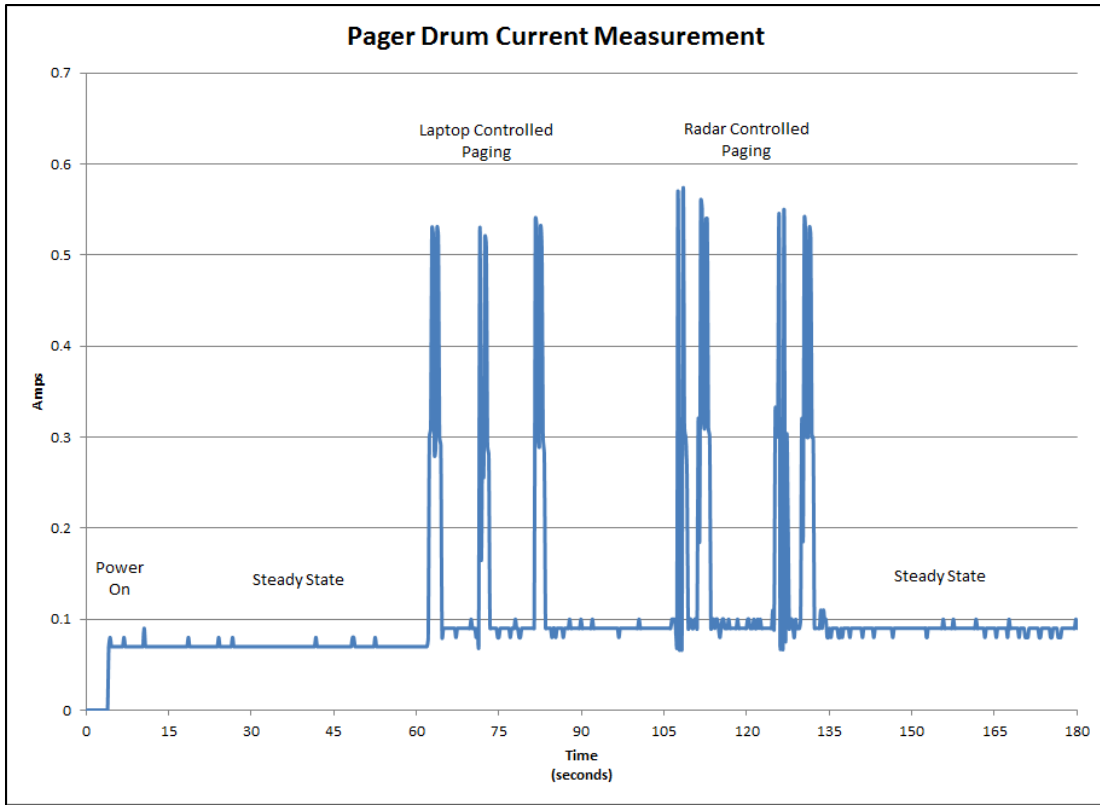
Figure 21: Pager Drum Current

4.2.1.2. Repeater Power

The repeater drum has two states: standby and transmit. See Figure 22. When the repeater is switched "on" it goes into standby mode and draws approximately 30mA. When pager transmitter transmits, the repeater re-transmits (repeats) the page drawing about 1400 mA.
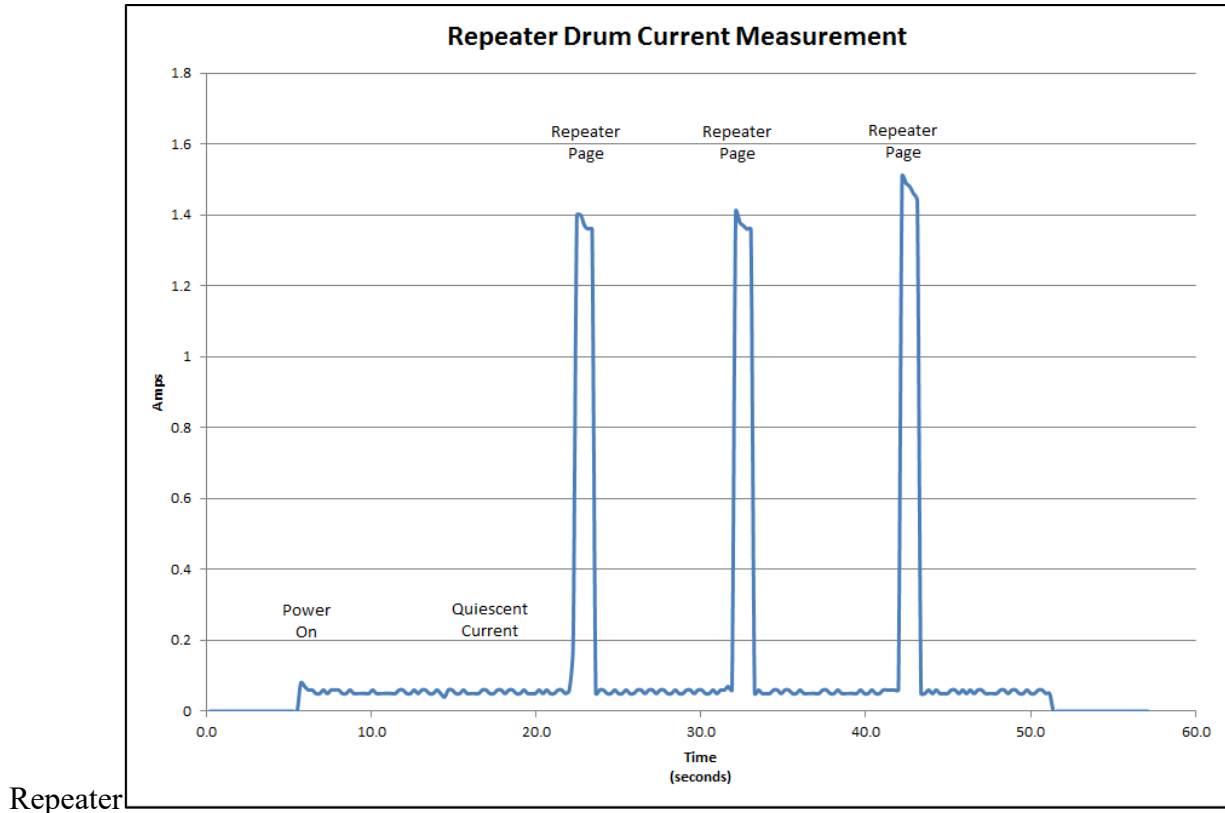
Figure 22: Repeater Drum Current

To relate the current draw to hours of operation before the battery needs recharging, divide the current draw into 13 amp hours (50% battery discharge). As an example, assuming the pager drum's paging 10% of the time, 0.54A x 0.1 + 0.09A x 0.9 = 0.13 A average draw so 13 Ah / 0.13 A = 100 hours. For this scenario the pager drum would operate 100 hours before needing to be recharged.

How often the pager drum needs to be recharged is a function of how often the transmitter is activated. It is expected that the pagers speed setting would be increased to keep the pager from operating more that 10% of the time.

5. DISCUSSION

The LRS pagers were evaluated for vibration intensity, usability and range. The vibration intensity was deemed adequate although the pager needs to be snug against the body to be effective when a person is actively working. A case sewn to a belt would transfer the vibrations to the body better than the belt clip provided. Also the pager must vibrate several times when activated to ensure the wearer notices. Usability was excellent due to its compact size and simplicity. Standard pager range was marginal for WTIs application due to its variability. WTI testing showed ranges from 300 feet to 1000+ feet although after the manufacturer suggested tuning the pagers, average range for the tuned pagers was 800 to 1100+ feet. See section 4.1.3 for testing details.

Pager range is affected by several variables:

- Pager location on the user, e.g. back pocket, belt, hard hat,
- Obstructions between transmitter and pager,
- Pager sensitivity,
- Transmitter power setting and,
- Transmitter antenna location.

The pager should be located as high on the user as practical but also must be held snugly against the body for effectiveness. Line-of-sight between the pager and transmitter provides the longest range but is not always possible in a work zone due to obstructions and body position. Pager sensitivity varies considerably between un-tuned pagers; requesting "tuned" pagers from the manufacturer assurers more uniform performance and maximum range. Transmitter power is typically adjustable and normally set to maximum so optimally antenna placement, as high as practical, provides the best pager range.

6. CONCLUSIONS

On June 19th the pagers were triggered at 12:18 PM while the project team was videotaping traffic. By aligning the time stamps of the pager log file, the speed log file and the HD video, an image of the speeding vehicle was identified. Note the image matches the vehicle observed by the project team.

Utilizing the image from the HD video and overlaying applicable sections of the master's pager and speed logs, the image shown in Figure 23 was created. The image shows the vehicle, the pager trigger, the speed above 75 mph, and the warning lights illuminated, confirming the WTI system's successful operation.

Figure 23: Frame Capture of Speeding Vehicle - WTI Image

In conclusion, the range testing showed that tuned pagers have approximately twice the range of an unturned pager, a ground plane improves range, and if tuned pagers are used a repeater may extend the range to over 3000 feet.

7. RECOMMENDATIONS

The following items are recommended for further research:

- Custom pager case or belt to better transfer vibrations to the wearer.
- Research custom designed paging system for transportation use.