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16. Abstract <p>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 results of the project are a system of 30+ smart traffic drums was developed, the system was tested for four weeks on SR 152 near Los Banos, CA, the system detected speeding vehicles and synchronously flashed the warning lights, the pagers vibrated at the detection of a vehicle traveling 20 mph over the speed limit and daily deployment and retrieval of the system was labor intensive. Evaluation of speed data appears to show that the system does have an impact in reducing overall average speed and percentage of vehicles traveling at high speeds.</p>					
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# Executive Summary for the Western Transportation Institutes augmented Speed Enforcement System

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## EXECUTIVE SUMMARY

The purpose of Augmented Speed Enforcement (aSE) project was to detect and warn speeding vehicles to slow down in a work zone as well as providing warnings to work zone workers and the Maintenance Zone Enhanced Enforcement Program (MAZEEP) California Highway Patrol (CHP) officer. The Western Transportation Institute's (WTI) part of the project was to design, assemble and real world test a deployable smart drum (sDrum) system for rural area work zones. Warning lights warn the work zone workers and the speeding driver. A pager system warns the work zone workers and the MAZEEP officer of an excessively speeding vehicle. An independent contractor evaluates the effectiveness of the system.

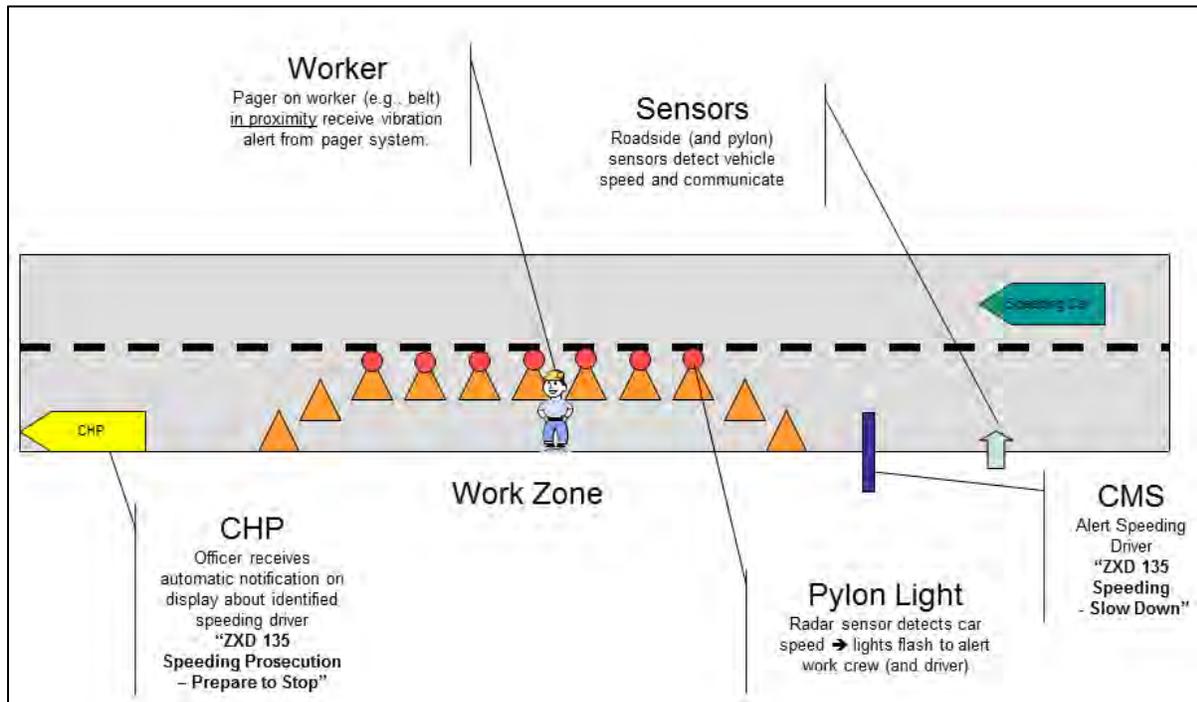
The project produced the following results:

- A system of 30+ smart traffic drums was developed;
- The system was tested for four weeks on SR 152 near Los Banos, CA;
- The system detected speeding vehicles and synchronously flashed the warning lights;
- The pagers vibrated at the detection of a vehicle traveling 20 mph over the speed limit;
- Daily deployment and retrieval of the system was labor intensive.

The project produced the following recommendations:

- Eliminate the necessity of tire rings;
- Improve pager coverage area;
- Minimize the number of drums in the system;
- Improve the radar range.

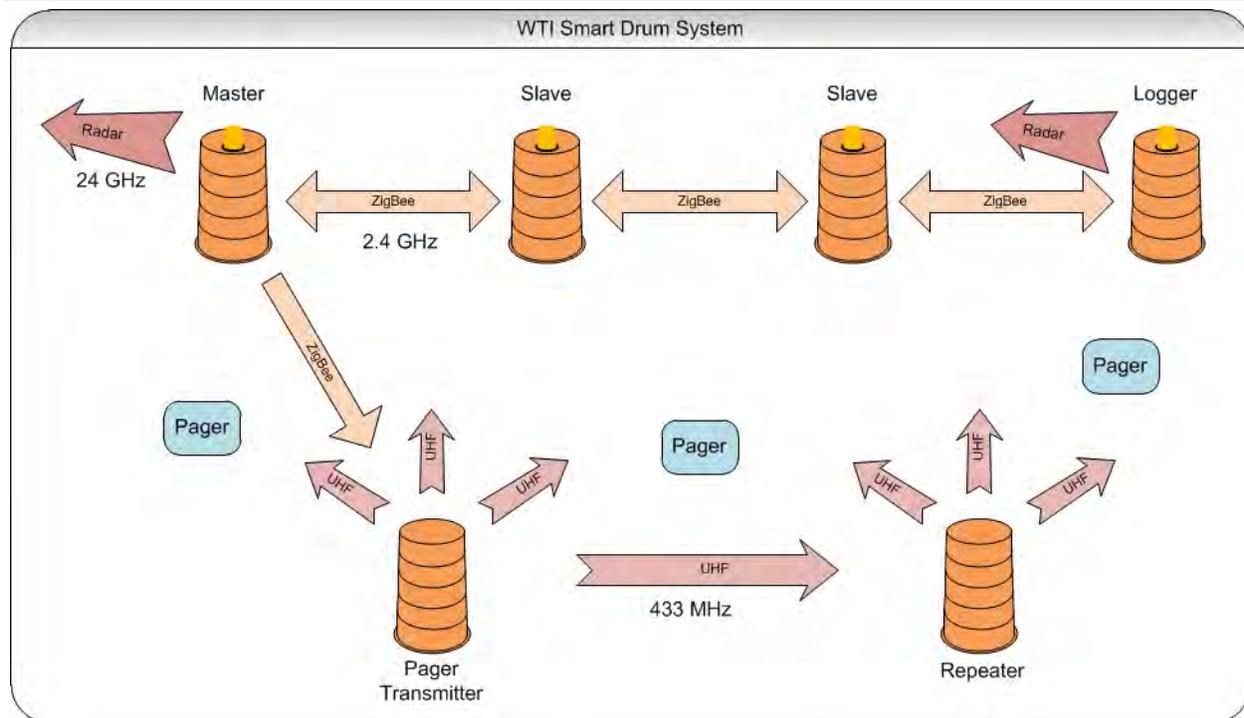
The purpose of this project, augmented Speed Enforcement (aSE), was to detect and warn speeding vehicles in a work zone as well as providing warnings to work zone workers. The project consisted of two systems, one provided by California PATH at UC Berkeley and the other developed by the Western Transportation Institute (WTI) of Montana State University. Either can be deployed independently or they can be deployed together. See Figure 1.



**Figure 1: aSE System Diagram**

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.

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 a 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 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. More repeater drums may be added to extend the pager's coverage if necessary.

The prototype system consisted of off-the-shelf components except for the light switch and frame which were custom-developed by WTI for the project. Traffic cones provided a compact enclosure enabling use of a small deployment and storage truck, easing deployment. The resulting system was called the "smart cone system" which was used for development purposes.

The pilot system consisted of the components developed in the prototype system but the enclosure was changed to a drum to make it more crash worthy. The drum provided a large enclosure enabling easy access to the interior thus eliminating the need for a frame. The resulting system was called the "smart drum system" (sDrum) and 30+ units were constructed for deployment. The sDrum system requires a large deployment and storage truck.

The sDrum has two main parts shown in **Error! Reference source not found.**: drum and base. The drum houses the radio and radar and has a warning light attached to the top. The drum is intended to be placed with the handle perpendicular to the direction of traffic with the light facing traffic. This orientation points the radar toward traffic. The radar is located at the top of the drum in **Error! Reference source not found.** and behind the four screws slightly below the light in **Error! Reference source not found.**



Figure 3: Open Master Drum - WTI Photo



Figure 4: Master Drum - WTI Photo

The WTI sDrum system was deployed as shown in Figure 5 for four weeks during May and June 2012 on State Highway 152 near Los Banos, California. The sDrum system was deployed independently from May 14<sup>th</sup> to the 18<sup>th</sup> and from June 11<sup>th</sup> to the 15<sup>th</sup>. From May 21<sup>st</sup> to the 24<sup>th</sup> and from June 18<sup>th</sup> to the 22<sup>nd</sup> both the sDrum system and the PATH system were deployed together. Additionally, baseline data was collected using only iCones during two separate weeks when no technologies were deployed on the roadway.

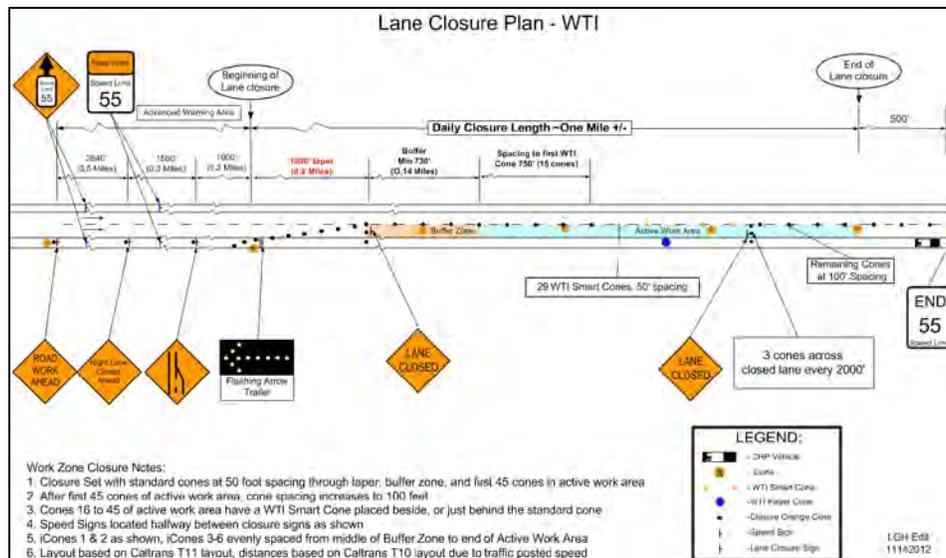


Figure 5: sDrum System Deployment – Modified Caltrans Image

The sDrum system consists of 28 orange traffic drums located adjacent to the orange cones marking the work zone closure. When the system detects a speeding vehicle approaching, it flashes the orange light on top of the drums to warn the driver to slow down and the workers of a speeding vehicle. See Figure 6. If the vehicle’s speed is above the pager’s set speed, the system also triggers a pager system to warn the workers and alert the MAZEPP CHP officer that a speeding vehicle is approaching.



**Figure 6: Warning Light Brightness – WTI Photo**

Pagers were given to maintenance workers and the CHP officer for evaluation; the project team also kept several pagers to evaluate. On June 19<sup>th</sup> 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 7 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 7: Frame Capture of Speeding Vehicle - WTI Image**

Deployment of the system was found to be labor intensive and time consuming since it needs to be deployed and retrieved every day and tire rings are needed to prevent the drums from moving out of position on a windy day. It took two or more people; one to drive the truck and at least one, preferably two, to deploy or retrieve the drums.

During the Los Banos deployment it was observed that there was noticeable variation in the distance of the speeding vehicle from the drums when the warning lights started flashing. Subsequent testing at the WTI Transcend laboratory was conducted to measure the distance variability in a controlled environment. Also, the question had arisen whether the drums would

work at 100 feet spacing instead of the 50 feet spacing used during development and deployment, which was also tested at Transcend. See Figure 8.

Ultimately it was determined that much of the observed distance variability could be attributed to the varied shapes of the vehicles and the built-in processing characteristics of the radar unit. The spacing test showed the radios were capable of reliable communication at 100 feet but further testing would be needed before committing to it for deployment.

This project demonstrated that a system of smart drums could be developed to meet the stated requirements. It also demonstrated that the system must be simpler to deploy for work zone personnel to embrace it.

Future research should consider minimum drums sets to reduce deployment efforts and evaluate optimal flashing light patterns and strategies.



**Figure 8: Radar Range Testing at Transcend Laboratory**

## **SPEED EVALUATION**

The WTI system does appear to have an impact on driver behavior as demonstrated by reduced average speeds and reduced percentages of radar reads of vehicle speeds greater than or equal to 60 mph at affected locations in the work zone. For instance, when the WTI system alone was present, there was a decrease in overall average speed of as much as 1.7 mph; and, when both systems were present, there was a decrease of approximately 2.4 mph in the areas affected by both systems. When the WTI system alone was present, approximately 25% of vehicles entering the affected area at 60 mph or above reduced their speed to below 60 mph within this same area, and even more (40%) did the same when both systems were in place. For the baseline, there was only a 10% reduction in this portion of the work zone. Where differences in the percentages are statistically significant and in portions of the work zone affected by both systems, the indication is that the configurations consisting of both systems, the PATH system alone, and the WTI system alone all showed improvement, demonstrated by reduced percentages of speeds 60 mph or greater over the baseline consisting of neither system (no treatment). This is consistent with our general hypothesis regarding the expected impact of these systems.

There are also statistically significant differences in the percentages at locations preceding the systems, which indicate that other factors should be considered in order to make valid comparisons and conclusions, since these locations would not have been influenced by either of the systems. And, there are apparent reductions in speed during baseline weeks at the end of the work zone, which indicates that other factors are involved. For instance, the location of the CHP vehicle was sometimes at the beginning of the taper in the work zone and at other times at the end of the work zone during times in which the WTI system was in operation. The work zone itself was not in the same location throughout the evaluation period. Proximity to Los Banos, traffic to and from side roads and variation in the placement of the iCones also may have contributed general variability and specific differences between rates. As such, engineering judgment will be critical prior to deploying these systems, and further study is recommended.

Further detail may be found in the separate, detailed speed evaluation document entitled, “aSE Speed Data Evaluation for the Western Transportation Institute System.”

## **CONCLUSIONS**

Real world testing near Los Banos, California proved the WTI and PATH systems can operate together or solo. The WTI sDrum system functioned as designed without any issues but had shorter than optimal pager range. It also showed the full WTI sDrum system is labor intensive to deploy which would need to be addressed before the system would be commercially viable.

The WTI sDrum system successfully detects speeding vehicles and flashes warning lights to warn the speeding driver and the work zone workers. The pager system also warns work zone workers when a vehicle is speeding excessively.

Speeding drivers responded to the flashing lights as shown by brake lights that were observed by the project team when the warning lights started flashing. The brake lights may have been an indication that the drivers had not been aware that they were speeding or that they just realized someone was monitoring their speed; either way they slowed down.

## **RECOMMENDATIONS**

The following items are recommended for further research:

- Further research of light patterns
- Research of light pattern effectiveness.
- Research radio options for extended drum spacing or drum sets.
- Research radios and protocols for implementing complex light patterns.
- Research improving radar range.
- Enhance configuration and control software.
- Research the minimum number of drums and spacing required to be effective.
- Research spacing of drum sets (e.g. 4 drum sets at ¼ mi spacing).
- Research component alternatives to reduce cost and improve performance.
- Research the optimal number of repeater drums for complete zone coverage.
- Research custom designed paging system for transportation use.

The research tasks listed would expand and enhance the performance of the sDrum system and potentially reduce procurement and maintenance costs.