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16. Abstract

In this project, a speed alert and augmented enforcement system (aSE) was developed with a combination of sensing, image processing and recognition, wireless communication. The system includes a speed camera that captures speeding vehicles, and a changeable message sign that displays speeder's license plate number and measured speed, and a web page that allows police officers to monitor the incidence of violators traveling at excessive speeds. The aSE system was field tested for a work zone application on a rural highway. With data collected over multiple weeks, under a baseline scenario without the use of the aSE system and test cases with the system, it was shown that the system was effective in reducing the number of vehicles moving in excess of the speed limit.

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Executive Summary for the augmented Speed Enforcement System developed and tested by California PATH, University of California Berkeley

by

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SYSTEM OVERVIEW

With funding support from the Rural Safety Innovation Program (RSIP) of USDOT, the *augmented Speed Enforcement* (aSE) project is a joint effort between the California Department of Transportation (Caltrans), Western Transportation Institute at Montana State University (**WTI**), Partners for Advanced Transportation Technologies (**PATH**), and the Transportation Sustainability Research Center at the University of California, Berkeley (**UCB**). The California Highway Patrol (**CHP**) was a significant partner in this project.

The core research issue of this project was to investigate whether the deployment of an *augmented Speed Enforcement* (aSE) system could change driver behavior and reduce crash rates. This system differs from an *Automated Speed Enforcement* (ASE) system as the aSE system uses real time information about speed violators to support on-road enforcement actions by the California Highway Patrol (CHP). As a demonstrative case study in this project, the aSE system is developed and tested in an application for work zones in a rural setting.

The main function of this aSE system is to communicate relevant speed, violation, and hazard information to the stakeholders in the work zone context: the drivers, CHP officers, and workers. The system consists of two sub-systems, one provided by PATH and the other WTI. The two sub-systems can work jointly in an integrated manner as a whole but they can also be deployed and tested separately. This report is focused on the development and performance of the PATH sub-system while the description of the WTI system is given in a separate report.

The PATH sub-system is intended for two main objectives:

- For the drivers, the system is aimed at providing an enhanced feedback, by capturing specific vehicle information of vehicles traveling beyond the speed limit at the leading portion of a work zone. With the license plate number and measured speed displayed on a changeable message sign (CMS), the drivers are advised to reduce speed as they move through the work zone.
- For the CHP officers, the system is designed to provide alerts to their attention when there are vehicles traveling at excessive speeds. The officers may be positioned at the trailing end of a work zone, but they can receive and access the information about the violators. The system does not provide any automated functions of issuing citations but leave the evidence collection and enforcement duties in the hands of the officers.

Figure 1 depicts the primary components of the PATH sub-system, where it can be seen that the speed camera and CMS are located in the front portion of the work zone. The CHP officer is positioned at the tail end of the work zone, while he may also move to other locations within or outside of the work zone. The CHP officers receive alerts of speeding vehicles with an iPad that was used in the field test. The officer can decide whether or not to locate the vehicle and issue citations to the violators. The functional processes and the technologies involved will be explained in the next section.

The other separate sub-system is provided by WTI. Figure 2 shows an overall layout of the WTI sub-system. In the middle section of the work zone, a series of "smart cones" fitted with a light display (beacon) with a radar sensor that detect individual vehicle speed and synchronize the cone light display to "highlight" and follow any violating vehicle. This dynamic visual warning is intended to provide a visual warning to drivers violating the speed limit and to alert workers of a potential speeding hazard in the work zone. In addition, a local pager network was configured to automatically alert (vibration mode) those workers nearest the detected hazard. Readers should refer to the separate report on the WTI system for further in-depth descriptions.

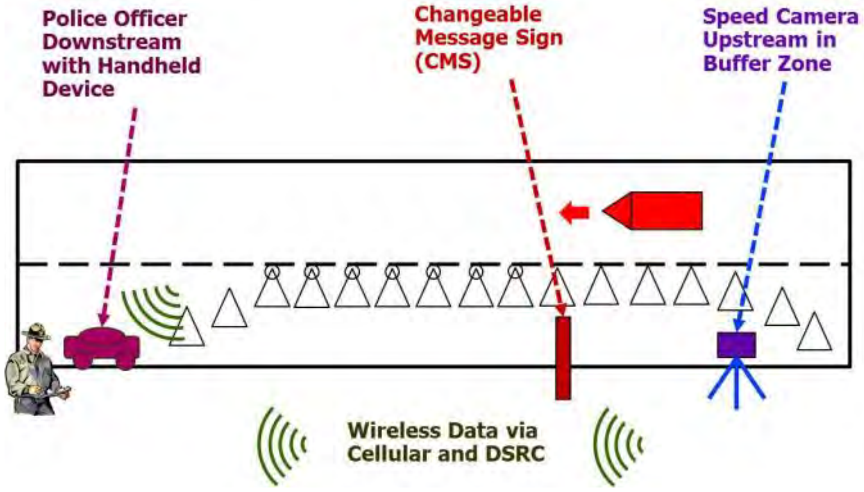

Figure 1. Augmented Speed Enforcement System – PATH Subsystem

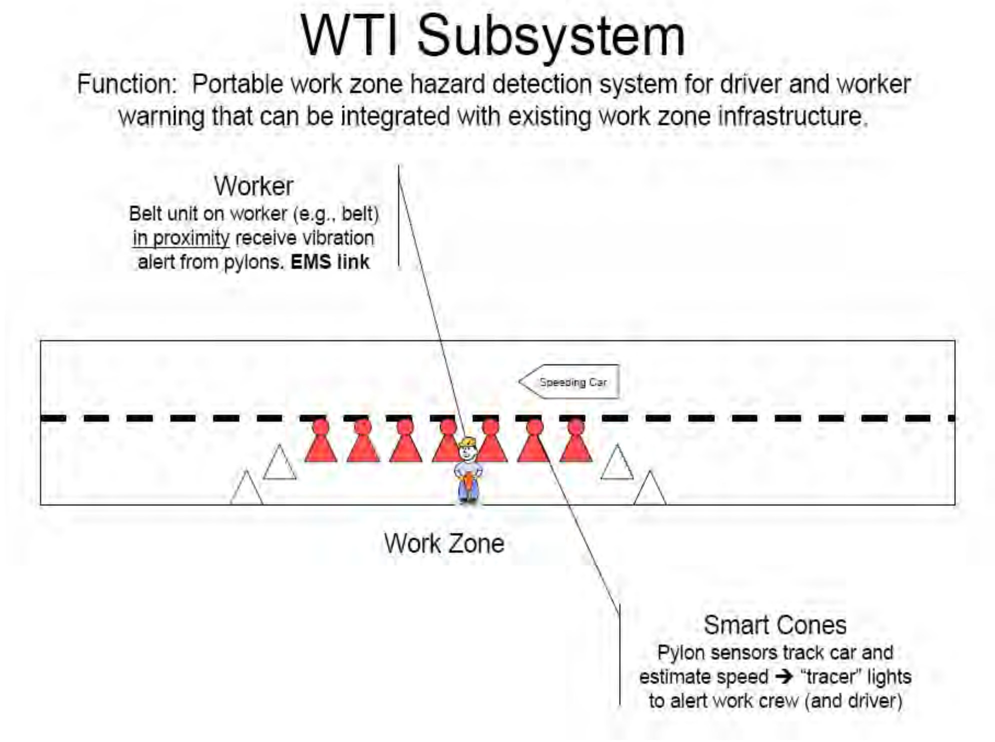

Figure 2. Augmented Speed Enforcement System – WTI Subsystem

PATH AUGMENTED SPEED ENFORCEMENT SYSTEM

The sub-systems developed and implemented by California PATH includes (i) the speed camera, (ii) changeable message signs, (iii) portable device displays to CHP officers, (iv) associated wireless communication links through Dedicated Short-Range Communication (DSRC) and Cellular Network embedded in the subsystems, as well as (v) a data server located at PATH headquarters.

Referring to Figure 1, the above-described system performs its functions in the following sequence:

- Speed camera system detects speeding target vehicles, captures photographs, and performs automatic license plate number recognition.
- The measured speed and license plate number are transmitted through a Dedicated Short Range Communication (DSRC) link and displayed on a downstream Changeable Message Sign (CMS), at a distance of 250-300 meters advising drivers to reduce speeds if they are over the speed threshold. Through this personalized message, drivers are encouraged to observe the lower speed limit as they pass through the work zone.
- The data, including speed, license plate numbers, and photographs, are also transmitted by a cellular connection to a back-end server and become accessible via any standard web browser by police officers stationed either at a downstream location, at a range of several hundred meters, or at a greater distance from the active work zone. The information is displayed to the officers on an iPad .
- The data are stored and archived at the local control computer within the speed camera system, as well as the back-end server. The back-end server allows remote monitoring and diagnosis of the operational status of the speed camera, and maintains archives of all captured and transmitted data.
- As implied by the functional sub-systems in (2) through (4) above, DSRC and cellular communication links are required to transmit specified data elements to CMS, police officers, and a central server.

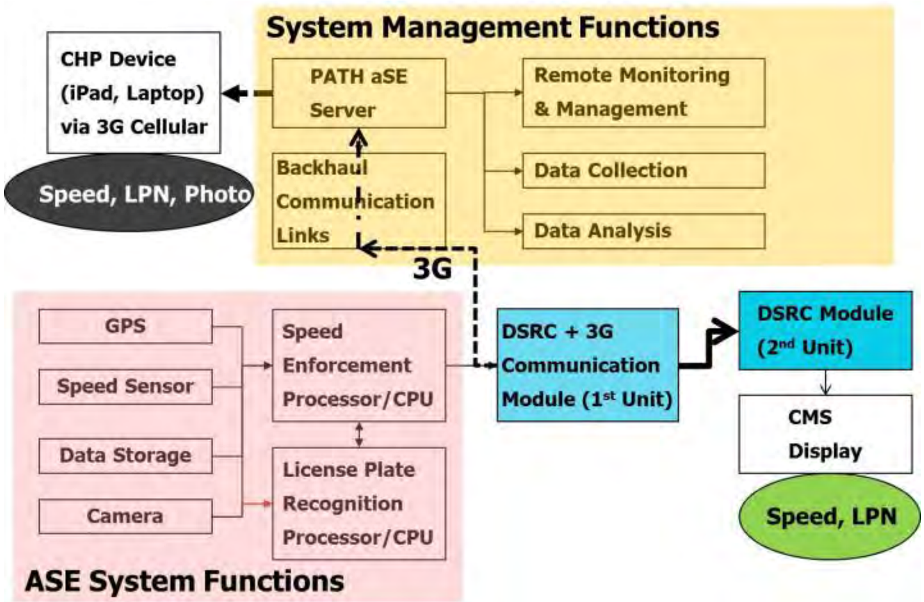

Figure 1. PATH Sub-system Functional Diagram

FIELD TESTS AND DATA COLLECTION IN LOS BANOS, STATE ROUTE 152

The PATH system was field tested in the summer of 2012. Over a period of 8 weeks, both WTI and PATH systems were deployed in conjunction with each other or separately to collect performance data. Field testing and data collection spanned the months of May, June, and July of 2012. The diagram below in Figure 6 provides an overall view of the work zone layout and WTI and PATH sub-system locations. The test site was on a section of State Route 152 east of the town of Los Banos. The actual work zone was set up on a day-to-day basis. The work zone, including the leading taper and buffer zones, stretched for approximately one mile.

Figure 4. Placement of Speed Camera

As shown in Fig. 4, the PATH camera/license recognition trailer was placed at the terminus of the taper zone, just behind the lane closed warning sign. A changeable message sign (CMS) was located downstream from the camera in the buffer zone, as shown in Fig.5.

Figure 2. Placement of CMS

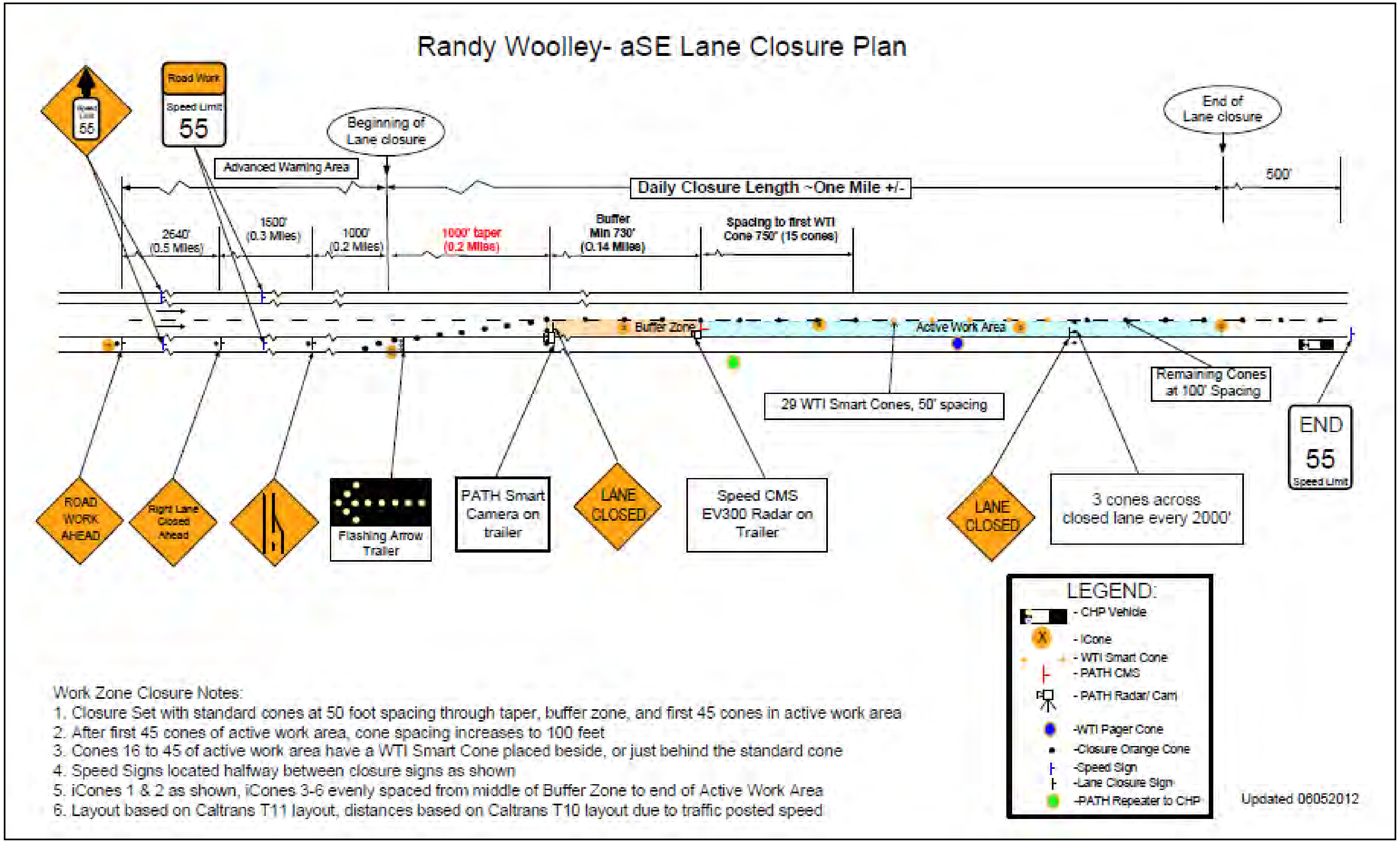

Figure 6. Work Zone Layout in Los Banos on State Route 152

The iCone safety drums were deployed throughout the testing period to collect traffic speed data. iCones are shaped as a bright orange traffic safety drum. They are equipped with backhaul communication links to upload the data when the devices are in operation and the communication links are available. As shown in the layout diagram of Figure 6, the first two iCones were placed upstream of the taper and buffer zones during the lane closure setup. The remaining four iCones were placed downstream in the lane closure, spaced to ensure that the radar units in the different systems would not interfere with each other. Data was collected throughout the lane closure. The iCones were used to capture speed data averaged using a two minute window and it also separately captured and reported high speed events.

DATA COLLECTION AND ANALYSIS

Several different types of data were collected and analyzed for evaluation of system performance during the field tests:

(1) The vehicle speed was measured by a radar sensor installed at the CMS location, which tracked the vehicles as they approach the CMS after passing the speed camera trailer.

A review of the radar data at CMS and results reveals that:

- A great majority of the vehicles show a reduction in speed as they approach the radar.
- There are a meaningfully large number of speed reductions among all samples, which is consistent with data samples from other data sources.
- Anecdotally, the researchers were able to observe occasional brake lights of vehicles when they approach the CMS. This also matches the noticeable numbers of significant speed reductions in data.

(2) The average speed of traffic at several locations along the work zone was measured by the iCones.

With the analyses of the iCone data, we examined the relative effectiveness of the PATH aSE system. A key measure of effectiveness of this project is the reduction in the percentage of high speed vehicles going over 65mph in the work zone and an increase in the percentage of vehicles going below 60mph. The analysis verifies the efficacy of the PATH aSE system over the baseline condition, with data related to Cone 4 is most affected by the PATH system. Hence we investigate this data more closely. The result of this analysis show that at this location, the PATH aSE system shows a very significant 68% reduction in the percentage of vehicles travelling over 65mph. and 6% in the percentage of vehicles travelling below 60mph relative to the baseline condition. This information confirms the usefulness and effectiveness of the PATH aSE system.

(3) The data transmission between communication modules and backend server were logged to estimate transmission time lags.

We analyzed transmission performances for different routing parts, where all results are measured and obtained from the field trials in Los Banos. Table 2 shows transmission latency of the three routing parts. As expected, in the first part, the speed camera is directly connected to the OBU using an Ethernet cable. Thus, the transmission latency between the OBU and speed camera is, on average, 0.321 milliseconds. And, in the second part, the DSRC achieves 0.694 milliseconds on average, transmitting a DSRC message from OBU to RSU. In the third part, due to a switch hub problem, the transmission latency is up to 94.497 milliseconds on average. While this is adequate for the purpose of aSE implementation, it represents a bottleneck among the transmission links.

	Camera<->OBU (ms)	OBU<->RSU (ms)	RSU<->CMS (ms)
Max	0.737	2.178	848.079
Min	0.273	0.66	1.567
Average	0.321	0.694	94.497

In the following table we summarize the data for both text and photo transmissions from the OBU module to the backend server. Of all these seven sets, we discard the fifth set while measuring the overall impact. The reason is the anomalous behavior of the system during that particular slot, due to malfunctioning of power supply. We also analyzed the individual behavior of the text and photo upload latency. The resulting cumulative average for the text upload latency is found to be 9.4 seconds and that for the photos is 27.01 seconds. Both these values are well within the bounds necessary for effective use of the cellular-server data link to transfer photos and text.

Text	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**	**Set 6**	**Set 7**
E2E Latency(seconds)	**21.023**	**7.1714**	**7.6**	**6.579**	**188.29**	**7.3333**	**6.697**
Total	43	35	10	19	7	24	33
Photo	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**	**Set 6**	**Set 7**
E2E Latency(seconds)	**71.5**	**23.343**	**18.5**	**14.526**	**155.11**	**16.657**	**17.556**
Total	48	35	10	19	9	35	45

CONCLUSIONS

This report describes an *augmented Speed Enforcement* (**aSE**) system that was developed, implemented and field tested by California Partners for Advanced Transportation Technology (**PATH**) of the University of California at Berkeley. The project was carried out with the goal of evaluating the effect of reducing traffic speed and minimizing hazards in a work zone in rural areas. Specifically, the PATH aSE system aims to offer enhanced feedback to drivers so they travel safely under hazardous conditions, such as a work zone, as well as to provide assistance for enforcement officers to carry out their duties. The PATH aSE system includes the integrated use of sensing, computing, and wireless communication technologies. At the leading portion of a work zone, drivers of vehicles traveling above the speed limit are alerted in a timely manner by a changeable message sign that displays their license plate number and vehicle speed. Information about vehicles traveling at excessive speeds is also made accessible by CHP officers who are stationed at the trailing section of the work zone and out of the sight of drivers, allowing the officers to perform their enforcement duties, as deemed appropriate.

Demonstrated as a case study where the aSE system can be suitably deployed, the system was field tested on California State Route 152 near the city of Los Banos. The tests were carried out with the PATH and WTI sub-systems individually and jointly deployed to evaluate the effects of traffic movement in comparison to the baseline of a regular work zone. The four scenarios, baseline, PATH system only, WTI system only, and both systems, were tested for one week each and the cycle was repeated with a total of eight weeks of data collected. During this period, Caltrans maintenance crew performed regular maintenance work on a stretch of SR-152 on a rotating basis.

Results from the field tests show that the system was indeed effective in reducing the number of speeding vehicles. Based on the iCones data that were placed throughout the work zone for the duration of the field tests, the percentage of vehicles traveling in excess of 65 mph was significantly reduced. For example, the summation of percentage of vehicles moving faster than 65-mph from all six iCones decreased from 60.23% in the baseline scenario to 54.13% in the scenario when the PATH aSE system was in place. This denotes a 10% reduction in vehicles travelling over 65mph in the work zone, relative to baseline conditions. Specifically, data at the 4^{th} iCone, which captures the most relevant effects of the PATH aSE system, shows a very significant 68% reduction in the percentage of vehicles travelling over 65mph. We also noticed an increase of approximately 6% in the percentage of vehicles travelling below 60mph at the 4^{th} iCone. These reductions of higher speed vehicles and increase of lower speed vehicles are measured relative to the baseline condition. These results further highlight the effectiveness of the PATH aSE system.

PATH also carried out additional field testing activities to support the utilization of Dedicated Short-Range Communication (DSRC) for the augmented speed enforcement (aSE) project. The main objectives of this DSRC experiment are to 1) identify the effective range up to which DSRC can support the requirements of the aSE project, 2) verify the benefit and necessity of specialized antenna and cables in extending the range along with the utility of using a repeater. The tests were executed in a suburban and rural setting in the city of Petaluma, CA. The results of DSRC testing indicated that with more sophisticated setup, the equipment can support successful transmission of data in a range of longer than one mile.

RECOMMENDATIONS

The PATH aSE system developed and validated in this project has the potential to be deployed for a wide range of highway segments, either in rural or urban areas. At locations where speeding is a concern, the augmented speed enforcement can be used to provide timely and enhanced driver feedback, achieving the primary objective of reducing traffic speeds to avoid hazards. Significantly, enforcement duties remain in the hands of officers, and the use of this system does not lead to legislative concerns in jurisdictions where automated functions are prohibited.

The following items are recommended for further research and field operational tests:

- Further research of operational effects on driver behaviors, which can be enhanced by more systematic data collection and planned driver feedback and survey
- More in-depth data collection in different operating scenarios and roadway environment
- Operation in diverse environment, such as incident zones and high-risk locations with speeding hazards.
- Research on the configuration of system components to facilitate easy field deployment, including the packaging of speed camera, wireless communication modules, interface between sub-system components.
- Field operational tests with Caltrans and Highway Patrol to allow evaluation of potential system users and improvements based on user feedback.

The research tasks listed would expand and enhance the performance of the PATH aSE system and the readiness of deployment.