An Innovative Intelligent Awareness System for Roadway Workers Using Dedicated Short-Range Communications

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CONNECTED VEHICLE/INFRASTRUCTURE UNIVERSITY TRANSPORTATION CENTER (CVI-UTC)

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An Innovative Intelligent Awareness System for Roadway Workers Using Dedicated Short-Range Communications

Prepared for the Research and Innovative Technology Administration (RITA);
U.S. Department of Transportation (US DOT)

Grant Project Title:

Advanced Operations Focused on Connected Vehicles/Infrastructure (CVI-UTC)

Consortium Members:

Virginia Tech Transportation Institute (VTTI),
University of Virginia (UVA) Center for Transportation Studies,
and Morgan State University (MSU).

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EIN: 54-6001805

Grant Funding Period: January 2012 – July 2016
Reporting Period End Date: January 1, 2017
Final Research Reports

October 15, 2015

Disclaimer

Connected Vehicle/Infrastructure UTC

The mission statement of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) is to conduct research that will advance surface transportation through the application of innovative research and using connected-vehicle and infrastructure technologies to improve safety, state of good repair, economic competitiveness, livable communities, and environmental sustainability.

The goals of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) are:

- Increased understanding and awareness of transportation issues
- Improved body of knowledge
- Improved processes, techniques and skills in addressing transportation issues
- Enlarged pool of trained transportation professionals
- Greater adoption of new technology

Abstract

Roadside workers and emergency responders, such as police and emergency medical technicians, are at significant risk of being struck by vehicular traffic while performing their duties. While recent work has examined active and passive systems to reduce pedestrian collisions, current approaches require line of sight using either laser-, infrared-, or vision-based systems. We addressed this problem by developing a Global Positioning System (GPS)-based solution that equips roadside workers and vehicles with GPS units to estimate the trajectory of oncoming traffic, and to estimate whether worker strike is imminent. The results of our study show that our approach is 91% accurate in alerting the worker and vehicle of collisions and near misses. Furthermore, accurate warnings can be provided 5 to 6 seconds before any potential collision, allowing time for mitigating solutions.

Acknowledgments

The principal investigators would like to acknowledge the authors of this report: Jason Forsyth, Kristen P. Hines, and Eloise Coupey. The authors also wish to thank Jacob Dennis, Mary Lee Carter, and Bryan Faulkner for their comments on earlier drafts.

Table of Contents

Background 1

Method 2

- Problem Definition 2
- Worker Warning System 3
- Experimental Setup 3

Results 5

Discussion 6

- Performance Factors 6
- Impact of Monitoring Distance 7

Conclusions and Recommendations 8

Appendix: Commercial Feasibility of the InZoneAlert System 11

- Strategic Plan: Mission, Goals, and Core Competency 11
- Situation and Stakeholder Analysis 11
  - Industry Analysis: Roadway Construction 11
  - Industry Analysis: First Responder Markets 12
  - Industry Analysis: Additional Vehicle/Mobile Equipment × WOF Markets 12
  - Industry Analysis: Recreational Markets 12
- Marketing and Product Objectives 13

References 14

List of Figures

Figure 1. Worker-vehicle collision model. 2

Figure 2. Experiment test cases: collision (A), near miss (B), and clear miss (C). 4

Figure 3. Boom extension for test Condition A with “worker” DSRC radio shown in the road.... 5

Figure 4. Testing location looking toward the vehicle’s starting position. Worker DSRC radio shown in foreground. 5

Figure 5. Linear estimator error when predicting closest approach of worker and vehicle............ 6

Figure 6. Warning time and accuracy at 56 km/h (35 mph). 8

Figure 7. Example vest drawing (left) and implementation (right). 8

List of Tables

Table 1. Warning System Confusion Matrix 6

Background

Working alongside motorways and highways is dangerous. Examining injuries on highway construction projects in New York between 1993 and 1997, Bryden and Andrew found that 15% of all serious injuries were caused by vehicle accidents, two-thirds of which were caused by vehicles straying into the work zone [1]. These areas are also dangerous for law enforcement officers and emergency responders. From 2001 to 2010, 118 law enforcement officers were struck by a vehicle and killed. Of these 118 deaths, 37% occurred during duties like traffic stops and roadblocks, while the majority (63%) occurred while directing traffic or assisting motorists along the roadway [2]. The Bureau of Labor Statistics (BLS) also estimates that approximately six percent of firefighter fatalities from 1992 to 1997 resulted from being struck by a vehicle while either directing traffic or conducting roadside emergency rescues [3].

With the advent of intelligent transport networks, new technologies, such as adaptive cruise control, lane departure warnings, and automatic braking for collision avoidance, have been created to address roadway injuries and fatalities [4]. One approach applies computer-vision technologies that scan the path of the vehicle for pedestrians as a way to reduce pedestrian injuries. Once pedestrians are detected, the driver can be alerted, automatic braking applied, or autonomous evasion maneuvers taken by the vehicle [5, 6]. For example, stereo cameras have been used to provide a three-dimensional (3-D) forward view of the road in order to prevent and avoid collisions [7, 8]. In another work, multiple cameras around the vehicle created a bird's-eye view of the surrounding area to aid in parking lots or other areas where pedestrians may approach from multiple directions [9].

As with all computer-vision applications, this approach can suffer from occlusions such as trees, buildings, or other vehicles on the road [7, 10]. Specific to our problem of detecting roadway workers, work zones can have significant clutter due to construction vehicles, materials, and movable barriers. Part-based classification has been attempted to recognize "parts" of a pedestrian rather than a whole person to deal with occlusions [11]. A different group used part-based classification to create models of pedestrian movement to distinguish people from other objects [12]. Infrared cameras can also be used to detect the "heat signatures" of pedestrians [13, 14]. Alternatively, laser and radar systems have been used, as they provide highly accurate ranges (up to 135 m at ±5 cm) to forward targets [10]. However, these systems can often be confused by a multitude of objects due to ground clutter.

While all of these approaches can be highly accurate (85% to 100% at 35 m [7]), they all require line of sight to the target for detection. Roadside workers that are occluded by dense traffic, construction materials, or around a curve or hill in the road will not be detected. Thus, we propose equipping roadside workers and vehicles with Global Positioning System (GPS) units and enabling them to share position information via Dedicated Short-Range Communications (DSRC). These local networks can be used in conjunction with existing approaches to protect this class of pedestrians. Additionally, having both vehicles and roadside workers in the detection process enables both parties to develop their own warning estimates and take independent corrective action. While GPS positions are less accurate than existing approaches (approximately 2.5 m for 50% of positions [15]), we will show in this work how, on straight segments of road, a GPS-based system can distinguish between collisions, near misses, and total misses with 91% accuracy. This work is largely a feasibility study. To test our model for estimating roadside worker and car collisions, this work uses the simple case of a straight segment of road and does not address the more complex issue of detection on a curved roadside.

Method

Problem Definition

In this section, we outline our model for estimating roadside worker and car collisions. The primary metric is to determine how close a vehicle will approach the worker with sufficient time to provide a warning to the driver or the worker. We have assumed that both the worker and the vehicle can know their position via GPS and exchange information over some radio network. Also, to simplify our calculations, this model is only valid for a relatively straight segment of road. Given these assumptions, we can visualize this scenario in Figure 1, where a moving vehicle is approaching a worker. The blue dots represent the known positions of the worker and vehicle.

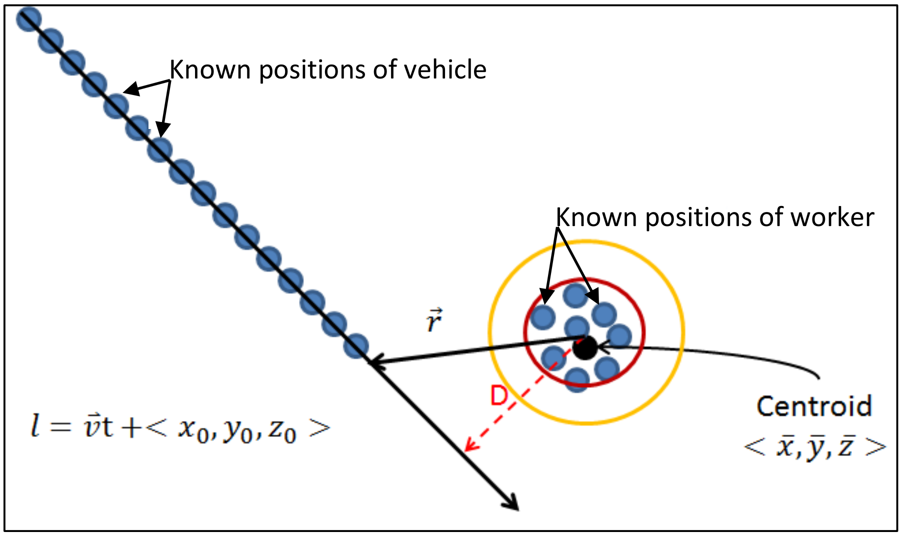

Figure 1. Worker-vehicle collision model.

To warn the worker about a potentially dangerous condition, the trajectory of the car must be estimated and compared to the position of the worker. We assume that both the worker and the vehicle know each other’s position and can estimate the approach distance. If the proposed system estimates that the car will approach too close to the worker, then it will issue an alert telling the worker of an impending danger. If the car will pass close to the worker, but not at a dangerous distance, a warning will be issued. These alerts/warnings are determined by comparing the linear distance between the vehicle's trajectory and the average position of the worker. In Figure 1, the trajectory of the car is given by $\vec{v}$, a trajectory that is estimated by using line l, and the position of the worker by $< \bar{x}, \bar{y}, \bar{z} >$. Given some vector $\vec{r}$ between the worker and the trajectory $\vec{v}$, the shortest distance between the two is simply: $D = \frac{\|\vec{r} \times \vec{v}\|}{\|\vec{v}\|}$. The vector $\vec{r}$ can be found from the most recent worker-vehicle distance, and $\vec{v}$ can be calculated using single-value decomposition of the vehicle's known positions.

Worker Warning System

A warning system can be created based on the closest predicted distance between the vehicle and the worker. First, we define two warning zones based upon the approximate distance between the worker and the vehicle. From the example in Figure 1, if the car were to pass close to the worker, as defined by the yellow circle, a warning would be issued. If the car were to pass within a dangerous proximity, marked by the red circle, an alert would be issued. On the other hand, if the vehicle does not pass close to the worker, no alert would be issued. Figure 2 shows a top-down view of the areas where an alert or warning would be issued. These distances are indicated by the red and yellow circles around the worker. During the warning and alert cases, the worker vest and car should only notify each other through messages and not through visual or auditory means.

Experimental Setup

To evaluate our warning system, data were collected on the Virginia Smart Road in Blacksburg, Virginia, using vehicle-to-infrastructure and vehicle-to-vehicle technologies. Two DSRC radios were used for the study, one attached to the test vehicle and another that was placed alongside the road to simulate the "worker." Each DSRC unit had GPS and Differential GPS (DGPS) capabilities, and could exchange messages with the other unit. DGPS was used to establish ground truth regarding how close the worker and vehicle approached.

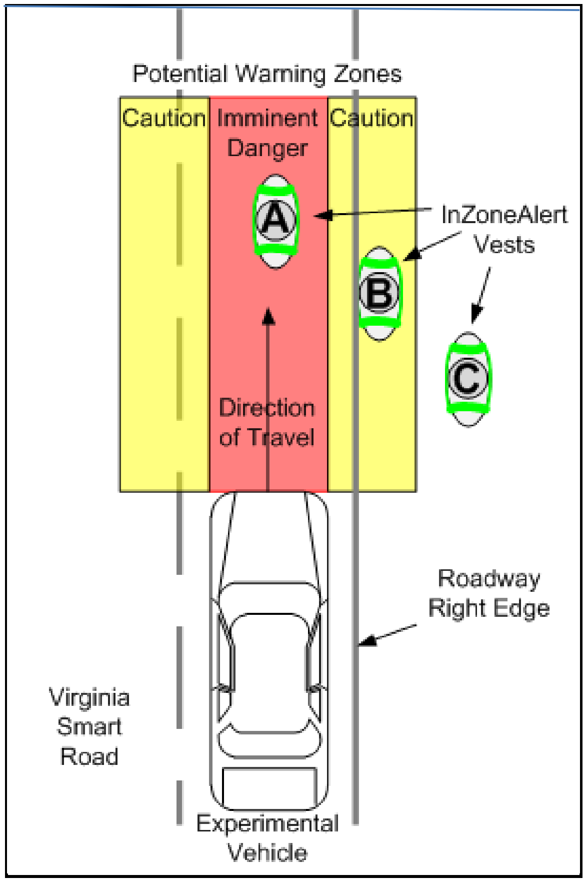

Figure 2. Experiment test cases: collision (A), near miss (B), and clear miss (C).

For this experiment, three test cases were devised: (A) a dangerous condition where the vehicle would strike the worker, (B) a warning condition where the vehicle would pass sufficiently close to the worker to be concerning, and (C) a negative condition where the vehicle was sufficiently far away that it would not pose a danger to the worker. These three positions are indicated in Figure 2 by the A, B, and C indicators. For Condition A, the vehicle passed directly over the "worker" DSRC radio. To test this situation without damaging the DSRC radio, a boom was attached to the test vehicle that extended four feet from the driver's side of the vehicle. This configuration allowed the test vehicle to "run over" the radio without damaging the unit. Figure 3 shows the boom extending from the test vehicle with the "worker" DSRC radio in the foreground.

In Condition B, the worker radio was moved to the edge of the road. For Condition C, the DSRC radio was moved 4 to 5 m (12 to 15 ft) off the road. For each condition, the test vehicle was driven past the "worker" unit three times. The vehicle would begin approximately 500 m (1600 ft) down the road, would accelerate to 56 km/h (35 mph), and drive in the lane until it passed the worker. Once the worker was passed, the vehicle would decelerate and return for another trial. Each trial took approximately 30 s. The experimental set up for these tests is shown in Figure 4.

Onboard video, vehicle diagnostics, and position information were stored during the trial and analyzed afterwards to determine the accuracy of the warning system. Accuracy was defined as providing the correct response based on the actual approach distance between the worker and the vehicle. Three passes by the vehicle were conducted for each position (A, B, and C), creating nine trials overall. Two experiments were conducted, one in January 2014 and one in February 2014, providing 18 trials overall. The results presented in this study combine both data sets. For these experiments, the warning system was set to issue a warning or alert at 100 m (330 ft). A warning would be issued if the vehicle was estimated to pass within 4 m (12 ft) of the worker. An alert would be issued if the vehicle was estimated to pass within 2 m (6 ft) of the worker.

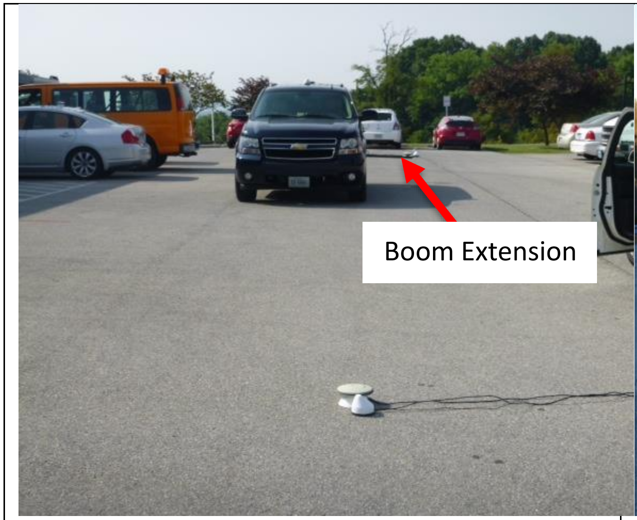

Figure 3. Boom extension for test Condition A with "worker" DSRC radio shown in the road.

Figure 4. Testing location looking toward the vehicle's starting position. Worker DSRC radio shown in foreground.

Results

Position data were collected during two experiments conducted in January and February 2014 using the setup described in the previous section. The data were evaluated offline to determine the feasibility of using GPS to estimate worker-vehicle collisions. For each trial run, the warning system would issue a response once per second based upon the estimated approach distance between the worker and vehicle. These responses were compared to the actual approach distance as determined by DGPS. Table 1 shows the confusion matrix generated by the warning system and compares the intended responses of the system to the actual ones that should have been issued. Precision and recall for the warning and alert conditions are reported as well.

Table 1. Warning System Confusion Matrix

Intended	**Actual**				
	Warning	**Alert**	**None**	**Precision**	**Recall**
Warning	304	71	0	0.81	1.0
Alert	0	519	0	1.0	1.0
None	50	0	396		

Discussion

The warning system exhibited 91% accuracy for all test conditions, where accuracy is defined as the percentage of time the system issued the correct response. When an inaccuracy occurred, the system would underestimate the approach distance, resulting in a more severe warning than was actually necessary. For example, in 50 cases no alert should have been issued, but the distance between the worker and vehicle was underestimated and a warning was issued. Similarly, in 71 cases a warning should have been issued, but a more severe alert was produced. While the system was inaccurate at times, it did not fail to recognize the approach of a car within the warning distance.

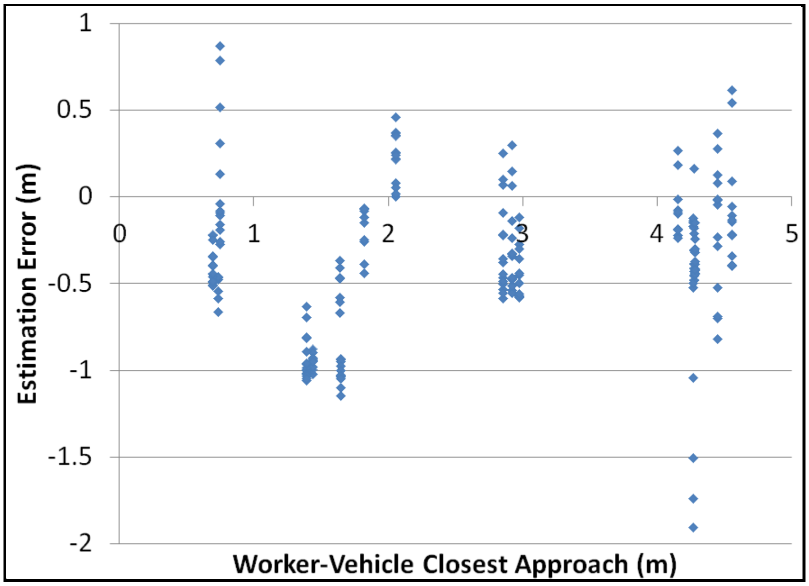

Figure 5. Linear estimator error when predicting closest approach of worker and vehicle.

For each data point in Table 1, the error in the approach estimator was calculated. Figure 5 plots the closest worker-vehicle approach distance determined with DGPS versus the estimation approach error. For a perfect estimator, all data points would on the horizontal axis. In this figure, most points lie below the axis, indicating that this approach typically underestimated the worker-vehicle distance.

Performance Factors

Analyzing the data in more detail, two factors affected the accuracy of the results: occlusion of the worker GPS, which resulted in loss of position accuracy, and changes in the vehicle trajectory by the driver. When analyzing the January 2014 data, it was observed that the GPS position of the worker had a larger distribution than was anticipated. It was theorized that a vehicle parked near the worker DSRC radio had occluded several GPS satellites, resulting in a loss of precision. This concern was noted in the February tests, with all vehicles being kept further away, resulting in more accurate worker positions. The less-precise data were retained for the study as occlusions of GPS satellites may be common in real-world applications of the warning system.

Another experimental factor involved sudden variations of the vehicle's trajectory, either due to the driver or the condition of the road. To allow for testing Condition A in Figure 2, the test vehicle radio was attached to a 1.2 m (4 ft) boom extending from the side of the vehicle. Using the boom, the vehicle could "run over" the worker in Condition A without striking the "worker" radio. In a few cases, the test vehicle would "bounce," causing a displacement in its position. A likely location for the error is when the vehicle transitioned between the bridge and roadway, which can be seen in the background of Figure 4.

Impact of Monitoring Distance

A key parameter for the warning system is the distance between the vehicle and the worker at which warnings are issued. This parameter was initially set to 100 m (330 ft) for our analysis. At our test speed of 56 km/h (35 mph), warnings issued at 100 m (330 ft) would provide approximately 6 to 7 s of notice. Logically, warnings that are issued at a greater distance provide more time for corrective measures to be taken. However, greater distance also allows more time for the car's trajectory to vary, and predictions made at great distance may be inaccurate. Figure 6 compares the accuracy of the simulated responses provided with the amount of time before the car approaches the worker at a constant speed of 56 km/h (35 mph). Warnings provided 10 s before the worker and vehicle pass are 91% accurate, but the accuracy quickly falls off as warning time (and consequently warning distance) is increased.

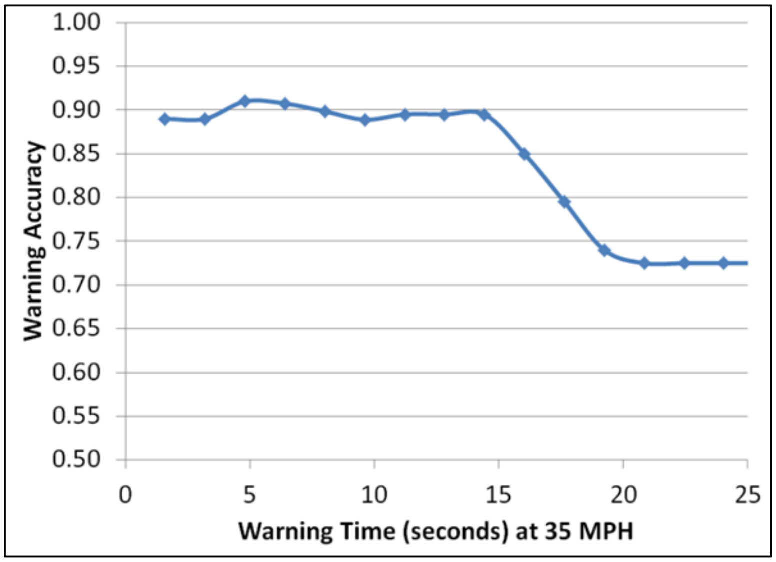

Figure 6. Warning time and accuracy at 56 km/h (35 mph).

Conclusions and Recommendations

A GPS-based collision detection algorithm for vehicle-pedestrian strikes has been presented. This initial study examined whether GPS positions alone could be used to estimate the approach distance between a roadside worker and an oncoming car. Experimental results show that the proposed warning system can distinguish between a near miss, complete miss, and collision with a worker with 91% accuracy. Our approach enables detection of roadside workers in situations where existing solutions may fail due to visual occlusions or environmental conditions.

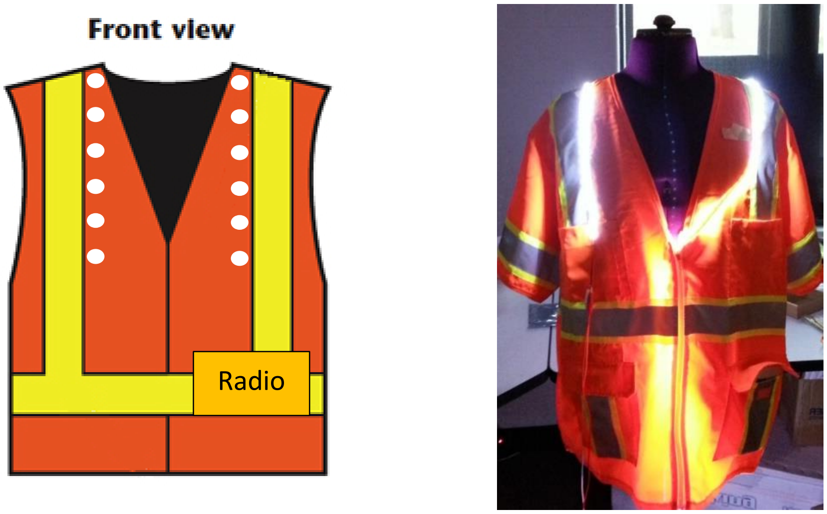

Figure 7. Example vest drawing (left) and implementation (right).

Future work will focus on creating wearable garment prototypes for roadside workers and providing proper responses to drivers to avoid collisions. This will be done by integrating a lightweight DSRC radio, equipped with GPS and Bluetooth, and personal alerting mechanism into a construction worker vest. Different prototypes that explore different alerting schemes, such as using auditory or visual cues to alert workers, will be created and tested in order to create an effective and unobtrusive alerting mechanism to protect the worker. An example prototype can be seen in Figure 7, where the radio is tucked away in a pocket and the circuitry used for the light-emitting diodes (LEDs) is in another pocket. Additionally, our collision-detection methods will be extended to more complex road segments, such as curves, and to allow for greater mobility of roadside workers.

Appendix: Commercial Feasibility of the InZoneAlert System

In this section we discuss the commercial feasibility for the intelligent traffic awareness system (the "InZoneAlert System") described in this report in order to translate this research into everyday practice. An understanding of the economic factors involved will increase the likelihood of InZoneAlert being adopted by the transportation and construction industries. We discuss a possible commercialization strategy, noting the influences on product development through industry, competitor, and stakeholder analysis. Next, we lay out the marketing and product objectives, and we discuss how the product strategy will capitalize on a staged rollout of customized systems, leveraging targeted markets to augment awareness and demand for the systems.

Strategic Plan: Mission, Goals, and Core Competency

On a broad level, our mission is to reduce the frequency of deaths and injuries from struck-by incidents between motorized or mobile equipment and individuals through use of a wearable, intelligent, traffic awareness system. Primary goals include rapid adoption of the system within the roadway construction industry, as well as by first responders (e.g., police and firefighters), followed by product introduction to other work sites that involve heavy mobile equipment and workers-on-foot (WOFs), such as warehouse and dockside logistics applications. A secondary market is bicyclists, whether commuting to work or cycling for recreation on roadways.

The InZoneAlert System is distinguished by its ready adaption and integration for use by WOFs. The computing technology that provides error-free alerts of impending incidents is unique in its ease of use, accuracy, and portability.

Situation and Stakeholder Analysis

Industry Analysis: Roadway Construction

In defined work zones, the risks for WOFs is clear. As noted previously, vehicle and mobile equipment movement around work zones results in significant numbers of injuries and fatalities in road construction every year. The road construction industry is a mature industry, with high levels of competition. Growth in road and highway construction is projected at an average annual rate of 1.6% per year from 2013 to 2018, reaching $53.7 billion in 2018. Government investment in the industry is a key driver behind the growth, as is evidenced by the Surface Transportation Extension Act of 2012 and the Moving Ahead for Progress in the 21st Century Act (MAP-21) [16]. Although funding for federal and state roadway construction projects declined during the U.S. recession, recent forecasts predict a constant and gradual increase over the next five years.

The private sector of the construction industry accounts for less than 25% of the total dollars attributed to roadway construction. Given the increases in private residential and roadway construction post-recession, growth in this sector suggests increased value for roadway worker safety systems.

Several characteristics of the industry make it a desirable early target, strategically. The industry exhibits low market-share concentration; that is, many smaller companies exist in the industry. That said, nearly half of new construction jobs are carried out by the top 5% of firms, size-wise. This statistic creates a viable point of entry for market penetration, as a less-fragmented market enables marketing efforts to be conducted in a focused and efficient manner. In addition, given the highly regulated nature of the industry, adoption of the InZoneAlert System may be a basis for firm differentiation and changes to existing safety requirements.

The maturity of the road construction industry suggests that while the industry still constitutes a viable target market—particularly with new funding earmarked under recent legislation—it is desirable to identify additional markets into which the traffic awareness system can be introduced.

Industry Analysis: First Responder Markets

As noted previously, first responders, including police and firefighters, face risk of struck-by incidents when called to emergency scenes. These undefined work zones create high levels of risk because of the uncertain presence, identity, and amount of vehicular traffic. Although the numbers of first responder deaths due to struck-by incidents is lower than that noted for the construction industry, the heightened risk of death or injury suggests that this is a strong target market for the system.

Industry Analysis: Additional Vehicle/Mobile Equipment × WOF Markets

Although the roadway construction industry accounts for many more dollars than other potential industrial target markets, the opportunities for identifying and penetrating these alternative targets may offset the size comparison. For instance, shipping ports where stevedores and other cargo handlers manage containers with mobile transport equipment are a possible target market. Similarly, warehousing and logistics management operations combine the focal characteristics of WOFs and the potential for harmful interaction with mobile vehicular or equipment threats.

Industry Analysis: Recreational Markets

Bicycle–vehicle collisions are a strong target of opportunity for the traffic awareness system. Fatalities from such collisions far outpace those noted in the roadway construction industry. The National Highway Traffic Safety Administration (NHTSA) reports that in 2011, 677 “pedalcyclists” were killed in collisions with vehicles [17]. Based on historical data from NHTSA, an additional 50,000+ cyclists tend to be injured each year.

Sizing up the marketing opportunity in this recreational market can be done with recourse to two figures: the number of bicycles sold, and the average cost per sale. Although the market for new bicycle sales has tended to increase year over year since 1995, the useful information is whether there are enough cyclists who are willing to spend money on safety equipment, and whether they comprise an accessible market. As bicycles increase in use as vehicles for daily function (e.g., commuting to work), the likelihood of collision may increase disproportionately compared with cyclists who pedal for fun on bikeways and trails.

Marketing and Product Objectives

As noted in the stakeholder descriptions, several distinct target markets offer potential for commercial success. With an anticipated cost to produce of $100, the price point for distribution within each segment can be established to encourage product adoption while balancing goals of increasing safety and profit.

A market introduction and penetration strategy should emphasize safety goals, suggesting that a staged strategy is preferable. Making the InZoneAlert System available to roadway construction workers initially would enable cost savings if the product leverages workers’ existing GPS and communications technologies (e.g., cell phones). Subsequent market entrance opportunities could build on workplace safety awareness campaigns, making first responders and alternative WOFs environments viable markets. These target markets each offer the potential for group purchases, as by government entities or construction businesses. The recreational market, given the absence of opportunities to leverage group purchases, is viewed as the last rollout.

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