Evaluation of Two Strategies for Improving Safety in Highway Work Zones

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During 1999, the Departments of Transportation from the states of Kansas, Nebraska, Iowa, and Missouri conducted a pooled-fund study of innovative devices designed to improve the safety and efficiency with which highway maintenance is conducted. In the state of Kansas, a total of nine devices were evaluated. This paper discusses the two devices that showed the greatest potential for improving the safety of highway work zones, a radar-triggered speed display and Lightguard lighted raised pavement markers (RPMs). The devices are described as they were evaluated, and the results are discussed with respect to the effectiveness of the devices relative to the current practice in Kansas. The speed display was also compared directly with active law enforcement at the same site. Speeds were used as a measure of effectiveness for both devices. Lane position was also used to evaluate the effectiveness of the Lightguard RPMs, which were used to delineate a crossover. In all cases, pneumatic hoses were used to collect the data. Data were collected for four days before and four days after the deployment of the speed display. Only one day of data was collected before and after activation of the RPMs. Both devices produced significant reductions in mean and 85th percentile speeds (statistically and practically significant). The RPMs resulted in a reduction in the percentage of passenger cars tracking within 30 cm (1 ft) of the edge line. The reduction was statistically significant at a 95% confidence level, though practical significance is difficult to assess in this case. Both devices were evaluated at rural interstate work zones. Further evaluation is needed to determine to what extent, if any, the effects of the devices decrease over time in a context with a high percentage of repeat traffic, such as an urban freeway. Key words: work zone, maintenance, traffic control, speed.

INTRODUCTION

The Midwest Smart Work Zone Deployment Initiative is a pooled-fund study, initiated in 1999, involving the four states of Nebraska, Iowa, Missouri, and Kansas. The purpose of the study is to identify and evaluate innovative technologies applied to making highway work zone operations safer and more efficient for the traveling public, as well as maintenance workers. With more than 214,000 km (133,000 miles) of public roads, the State of Kansas ranks fourth in the country behind California, Texas, and Illinois (*1*). Being responsible for maintaining 15,450 km (9,600 miles) of these public roads (*2*), the Kansas Department of Transportation (KDOT) places a high priority on work zone safety. As part of the first year of the ongoing study, nine evaluations were conducted in Kansas during 1999. For all evaluations, the devices were provided by the vendor at no cost to KDOT, and in exchange, KDOT funded the evaluation of the devices and the publication of the results. A summary of the results from all nine evaluations is available in the paper entitled "Midwest Smart Work Zone Deployment Initiative: Kansas Results" (*3*). This paper discusses in more detail the evaluations of two devices that showed particularly high potential for improving safety in highway work zones.

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The first device discussed is a commercially available radar-triggered speed display, provided by Speed Measurement Labratories (1-800-617-4929, www.speedlabs.com). The speed display resulted in significant reductions in mean speed, 85th percentile speed, standard deviation, and percent of drivers exceeding the posted speed. These effects diminished downstream of the device, but remained at statistically significant levels for the 0.8 km (½ mi) over which speed data was collected.

The second device discussed is a system of lighted raised pavement markers (RPMs) provided by Lightguard Systems, Inc. (1-707-542-4547, www.crosswalks.com). While the individual RPM units are commercially available, the configuration and application evaluated were experimental. The lighted RPMs resulted in a significant reduction in speeds and an improvement in lane keeping by passenger cars.

DATA COLLECTION

All data was collected using pneumatic hoses connected to automatic traffic recorders. Speeds were collected using paired hoses with a 6 m (20 ft) spacing. Raw data (i.e., time stamped axle hits) were recorded and post-processed to obtain vehicle classification and per-vehicle speed data. Data was analyzed separately for passenger cars and trucks and for daylight and nighttime conditions. In order to remove the effects of platooning, only records with an associated headway of 5 seconds or more were considered, based on the Highway Capacity Manual's recommendations for estimating percent time delay (*4*). Throughout the analyses, statistical significance was determined using a 95% confidence level.

RADAR-TRIGGERED SPEED DISPLAY

The speed display evaluated comprised a back-lit dynamic speed display, a standard speed limit sign posted above the display, and a strobe flash, all contained in a trailer mount. The strobe flash was set to activate when a vehicle's speed exceeded 103 kph (64 mph). A second threshold speed could be set that activated an alarm horn. The horn would sound toward the construction zone to alert workers that a vehicle was approaching at a potentially reckless speed. A maximum speed could also be set for the display, discouraging drivers from competing to post higher speeds on the display. Only the strobe threshold was set for the evaluation period. The device is bulletproof to withstand substantial vandalism attempts. The device is camera-ready to allow photo enforcement, although no camera was used in the evaluation (Photo enforcement is at this time prevented by state statute. In order for a citation to be issued, an offense must be witnessed by a law enforcement officer present at the time of the offense.).

Test Site

The evaluation was conducted in an 8 km (5 mile) construction zone on I-70 approximately 44 km (30 miles) west of Topeka, Kansas. The test was conducted using eastbound traffic during the second phase of a reconstruction project in which the eastbound lanes were closed, and two-way traffic was being carried in the westbound lanes. Originally, data was to be collected at ten locations in the vicinity of the device. Equipment failures resulted in usable data being obtained from only four of the collection points during the time the speed display was operating.

Data Collection

Prior to the deployment of the speed display, a week of baseline data was collected, followed by a week in which radar drones were deployed and more data collected. The week following the deployment of the speed display, the Kansas Highway Patrol (KHP) provided active speed enforcement for a total of 8 hours, recording the times during which an officer was present so that the corresponding data could later be identified. A fifth data set was included in the analysis, comprising the hour immediately following the departure of the KHP.

Results

Figures 1 and 2 show the speed distributions at data point 7 during the day, for passenger cars and for trucks, respectively. Figures 3 and 4 show similar data for data point 4. Vehicles passed over data

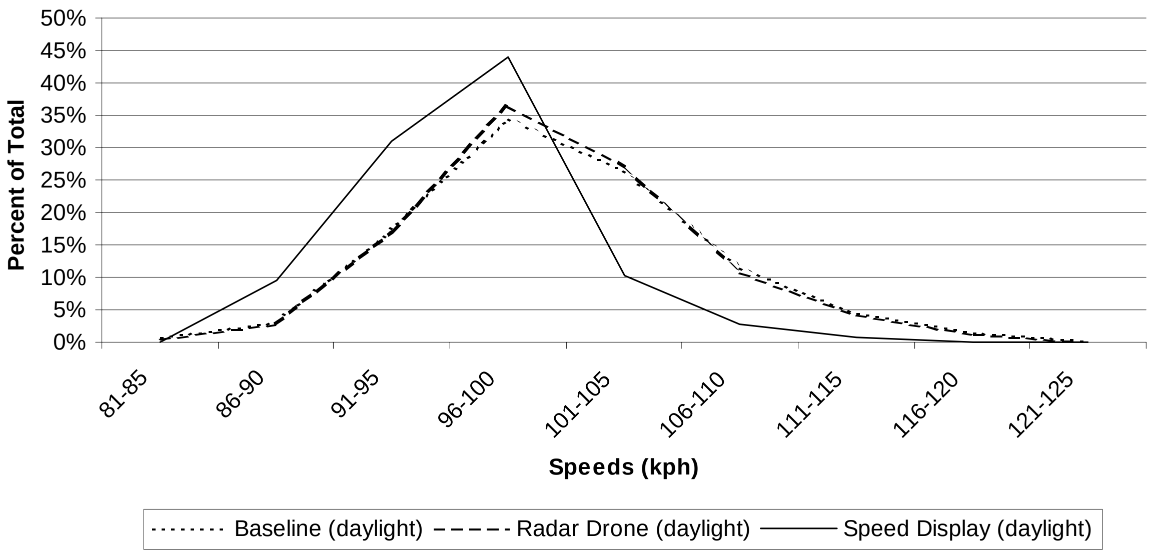

FIGURE 1 Speed distributions for data point 7 (daytime, passenger cars)

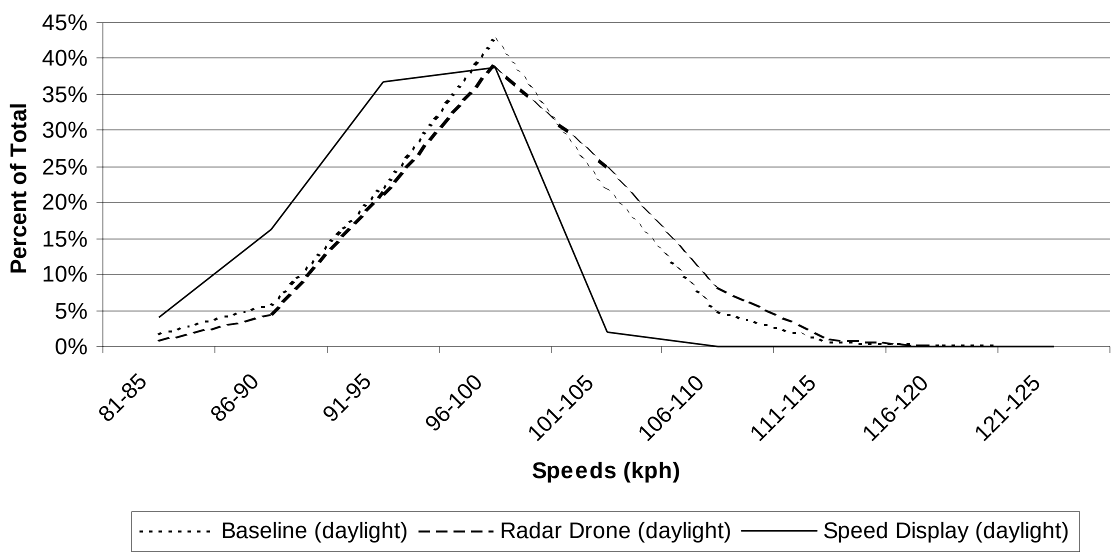

FIGURE 2 Speed distributions for data point 7 (daytime, trucks)

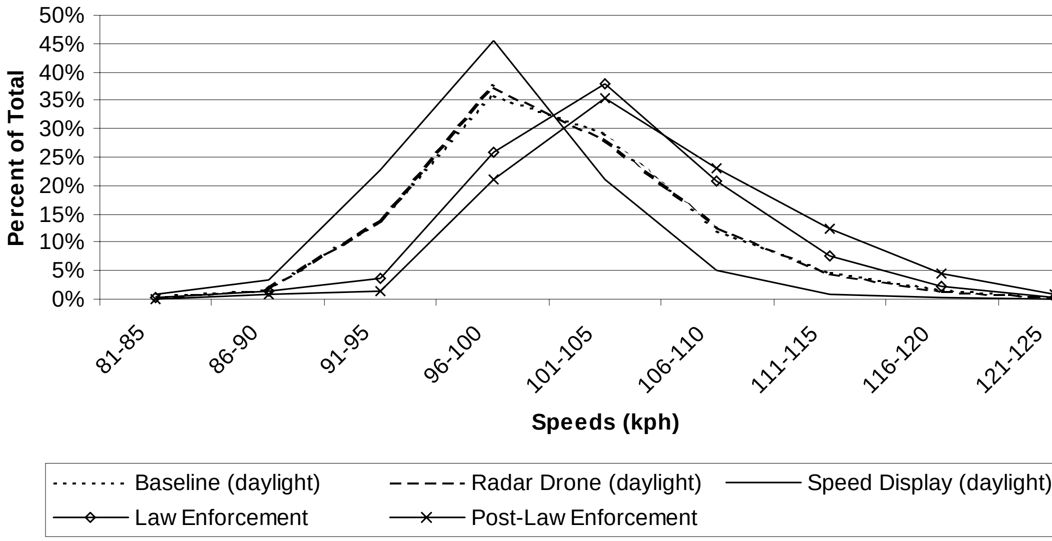

FIGURE 3 Speed distributions for data point 4 (daytime, passenger cars)

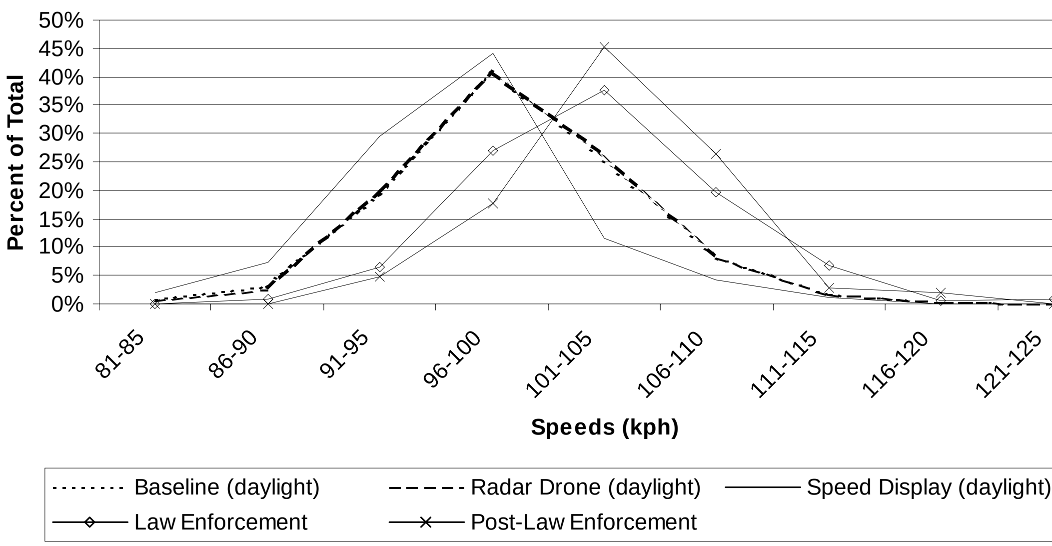

FIGURE 4 Speed distributions for data point 4 (daytime, trucks)

points in reverse order, i.e., data point 10 was the farthest upstream of the data points, while data point 1 was farthest downstream. The speed display was deployed near data point 7 at a median crossing. KHP locations were not recorded, but it is likely they were observing from the same location, because the shoulders were not suitable for parking and the median crossing near data point 7 would be the best location from which to observe traffic.

The radar drone showed little or no effect on speeds or on the percent of drivers exceeding the posted limit. In all cases, the speed display resulted in a significant reduction in mean speeds, 85th percentile speeds, percent of drivers exceeding the posted limit, and speed variation (standard deviations). While not appearing in Figures 1 and 2 due to equipment problems, data from data point 8 showed the impact of law enforcement on speeds to be almost identical to the impact of the speed display. However, data during the hour following the KHP's departure from the test site (i.e., those labeled "Post-Law Enforcement" in Figures 1 through 4), showed that speeds not only increased to normal, but *exceeded* baseline speeds. In Figures 3 and 4, however, it can be seen that during periods of active law enforcement, speeds were above the baseline, and rose yet higher following the KHP's departure.

Conclusions

From the data collected, it is reasonable to conclude that the radar drones are not effective devices for reducing speed-related traffic characteristics. The radar-triggered speed display was quite effective, reducing mean speeds, 85th percentile speeds, percent of drivers exceeding the posted limit, and standard deviations for both cars and trucks. The effects were less pronounced, but still significant, at data point 4, which is approximately 0.8 km (0.5 mi) downstream of the speed display. The display was easily deployed and very mobile. The setup time was less than 10 minutes once the site was identified. In contrast to the effects of the radar-triggered speed display, law enforcement appears to cause an increase in speeds downstream from the patrol car. Additionally, speeds continue to increase after the patrol car is no longer in the area. The reason for this phenomenon is unknown.

LIGHTGUARD LIGHTED RPMS

The Lightguard lighted RPMs were tested in an experimental configuration used to delineate a crossover in a rural construction zone. Amber lights were used to delineate the inside edge, placed just beyond the edge line, and white lights were used to delineate the outside edge, also placed just beyond the edge line. The lights operated in a steady-burn mode.

Test Site

The evaluation occurred at the westbound entrance to a rural interstate work zone on I-70 approximately 16 km (10 mi) east of Salina, Kansas. In the work zone, the westbound lanes were closed, and two-way traffic was being carried in the eastbound lanes. The Safety Warning System (SWS) was deployed at the lane taper on the westbound lanes, preceding the crossover where the RPMs were installed. The pavement in the crossover is 5.5 m (18 ft) wide with edge lines inset by 0.3 m (1 ft).

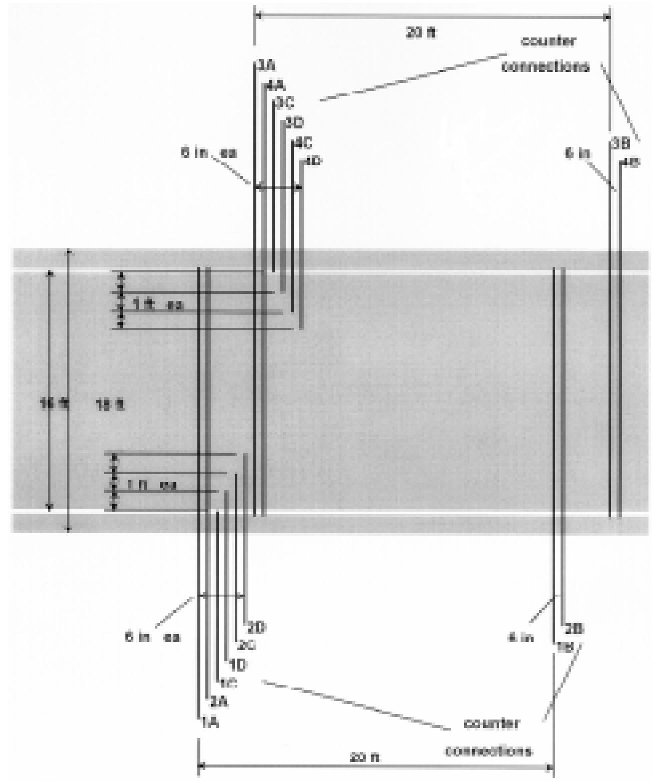

FIGURE 5 Hose configuration for measuring lane position

Data Collection

One day of lane distribution data was collected upstream of the taper, then the SWS was activated approximately 0.8 km (0.5 mi) upstream of the crossover. After data was collected for one day, the RPMs were activated and another day of data was collected. Two evaluation measures were used to evaluate the RPMs. The first measure focused on speeds (mean and 85th percentile) and the second measure on lane-keeping. The data was collected on the same schedule described for the lane distributions. To measure lane-keeping (and speeds, in the process), a configuration of hoses was set out as shown in Figure 5. Each of the short hoses detected a vehicle's encroachment into the area near the edge line, and the distance was determined by the distance the hose extended inside the edge line. The hoses were configured to count vehicles that tracked within 0.9 m (3 ft), 0.6 m (2 ft), and 0.3 m (1 ft) of the edge line, as well as those that crossed the edge line. Both edge lines were observed, requiring a total of 16 hoses and 4 counters for the full array. The A and B inputs for each counter were used to measure speeds, while the C and D inputs were used to track vehicle positions. Software was developed to use the speeds and times to match individual vehicles in the data sets produced by the four counters.

Results

During the first and third days of data collection, 16,856 vehicles were recorded. The lane-keeping data shows that only 11 vehicles actually crossed the edge line on the inside, and none crossed the outside edge line. Only 7 vehicles tracked within 0.9 m (3 ft) of the outside edge line. The only change that was significant at a 95% confidence level was that the percent of passenger cars tracking within 0.3 m (1 ft) of the inside edge line decreased from 8.9% to 5.2% after the activation of the RPMs.

The speed data revealed more dramatic effects. Figure 6 shows the speed distributions (in the crossover) for the three days of data collection (passenger cars). The distributions for trucks were very similar. For both passenger cars and trucks, the nighttime mean speed dropped by more than 10 kph (6 mph). The percent of drivers exceeding the posted limit decreased from 29% to 22% with the activation of the SWS, compared to 7% with the activation of the RPMs. The percentages for trucks were 25%, 23%, and 6%, respectively.

Conclusions

The RPMs resulted in a statistically significant improvement in lane-keeping among passenger cars. Other changes were not statistically significant. A much more dramatic effect was observed in the speed-related parameters, whose values decreased sharply with the activation of the RPMs. Because the installation was experimental, no conclusions can be made about either the required effort for installation, maintenance, or removal. The RPM units themselves were easily installed and removed, but the cabling necessary to power the lights could be an obstacle in some locations.

SUMMARY AND FUTURE RESEARCH

Speed reductions resulting from the deployment of the radar-triggered speed display were comparable to those occurring during active law enforcement. However, the speed reduction resulting from

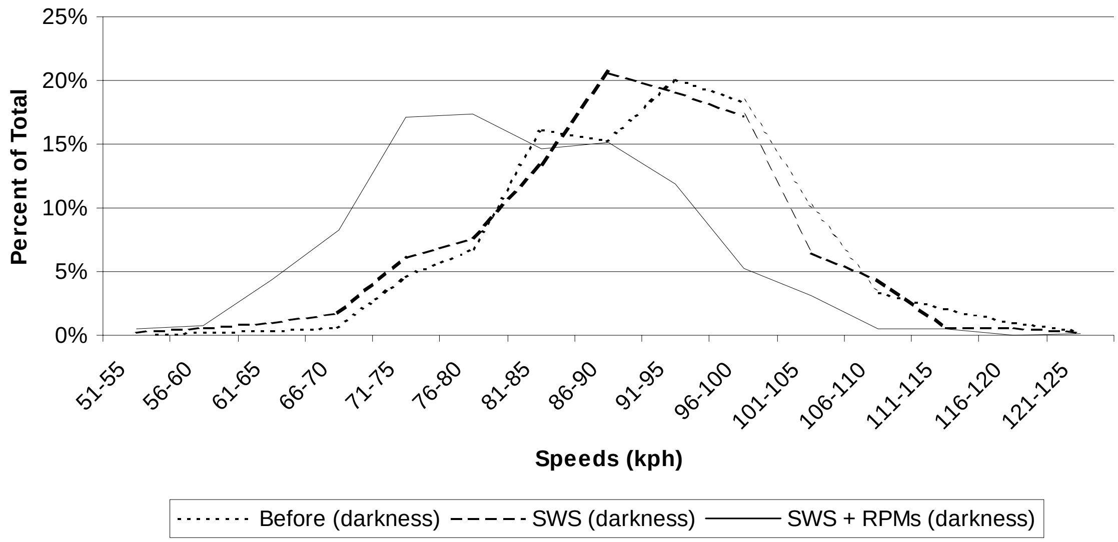

FIGURE 6 Speed distributions in the crossover(nighttime, cars)

the activation of the speed display propagated downstream to the last operational data collection point, while speeds actually increased at the same location during the periods of active law enforcement. The portability of the device, the ease of setup, and the sturdy construction are significant advantages. Ongoing tests in Texas and a planned test in Kansas during 2001 will further evaluate the effectiveness of this device, focusing on aspects such as the distance over which the speed reductions deteriorate and potential enhancements to the display such as complimentary signing.

The Lightguard RPMs resulted in substantial reductions in speeds and improvements in lane placement. Several enhancements might further improve the effectiveness of the RPMs, including a random flash mode for daytime operation, and a sequenced flash (chasing) mode for nighttime operation. Alternate colors are available, though colors other than the amber and white used in this evaluation might be considered a departure from *Manual on Uniform Traffic Control Devices* (MUTCD) guidelines. The system may be applicable to other situations, such as lane tapers.

Both evaluations were relatively short in duration. In the rural context in which they were conducted (i.e., very little repeat, or commuter, traffic), the results are probably typical of what could be expected in long-term deployments. However, further investigation is needed to examine the effectiveness of the devices in an urban context over longer periods of time.

In general, both evaluations evidenced strong potential for improvements in work zone safety through the deployment of the respective devices. Further research will likely be able to increase the benefits by improving both the effectiveness and the ease of deployment.

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