SPEED PHOTO-RADAR ENFORCEMENT EFFECTS IN HIGHWAY WORK ZONES SAFETY

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ABSTRACT

In this study we evaluate the safety effects of the first Speed Photo-Radar Enforcement (SPE) system that was implemented in highway work zones in the U.S.A. The self-contained SPE van is equipped with radars, a speed display sign to provide feedback to drivers about their approaching speed, and two high-resolution cameras to take pictures of the rear license plate of speeding vehicles and of the driver's face. Results indicate that the average speed of all vehicles was decreased by 6.7 to 7.2 mph at the SPE location, and similar reductions were observed by vehicle type (cars and trucks) and by travel lane (shoulder and median lanes). In addition, the SPE reduced the percentage of drivers traveling at more than 10 mph over the speed limit (-8.7%) and also increased the speed limit compliance by 75.5% for all vehicles together. Lastly, the headways of vehicles in platoons or for leader-follower pairs were not reduced when the SPE was deployed. Thus, on average drivers had more time to react to their leaders and the probability of rear-end collisions was lower, showing that SPE has potential as a speed reduction technique and also as a tool to maintain or improve safety in highway work zones.

1. INTRODUCTION

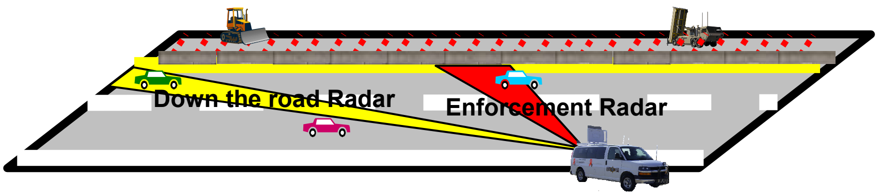
Road construction sites can be potentially dangerous for drivers and workers due to a wide variety of conditions including reduced speed, lane shifting or lane closures, and heavy equipment and workers at or around the work area. This is also evidenced by the high number of fatalities. The National Highway Traffic Safety Administration (NHTSA) reported 667 fatalities in the US work zones in 2009, and in 2007 there were 105 fatal occupational injuries at road construction sites, with a total of 720 fatalities in work zones.

Speeding is often a contributing factor to the frequency and severity of these crashes, thus reducing the speed of vehicles travelling in the work zone can significantly improve work zone safety for both drivers and workers. However, during the process of reducing the speed of vehicles it should be ensured that the headway of vehicles in not decreased, as the reduction in headways could increase the possibility of rear-end crashes and in general is not desired.

Speed Reduction techniques are very diverse and can range from educational campaigns, to direct speed enforcement. In this paper, the discussion is centred on the effects of using an automated Speed Photo-radar Enforcement (SPE) system on the speed and the headway of vehicles in highway work zones in the state of Illinois (U.S.A.). The Illinois SPE was the first system of this kind that was authorized to operate in highway work zones in the U.S.A.

The Illinois SPE system is self-contained inside a van that can be safely parked outside of the traveled lanes, parallel to the roadway. When deployed, the SPE van displays a speed feedback board (that uses conventional down-the-road radar) on the top of the van, visible to oncoming drivers. The system is also equipped with a more sophisticated "across-the-road” radar that measures the speed of vehicles when they are about 150 ft upstream of the van. This radar operates at a specified angle to the path of vehicles, and obtains accurate speed estimations by considering the angle effects. Finally, two on-board cameras are activated by the radar when a speeding vehicle is detected, and take pictures of this vehicle from the back of the van, and also from the front of the van (as it is leaving the van location). Then, these pictures are analyzed by SPE-trained Police officers inside the van and after approval the speeding citations are sent by mail to the registered vehicle owner. Figure 1 shows a SPE van, as well as a schematic view of its placement in work zones.

a) Photo enforcement vehicle.



b) Operation of the photo enforcement.

Figure 1. Speed photo enforcement van in work zones

SPE systems in general have been used as a speed control and enforcement tool in more than 40 countries around the world (1), and they have been found to be effective in reducing speeding in residential roads and freeway systems (2, 3, 4, and 5). Previous studies have also shown the potential benefits of SPE system in work zone speed enforcement (6), but the effects of the SPE on the speed and headways have not been studied altogether.

The implementation and field evaluation of the Illinois SPE was presented by Benekohal et al. (7, 8), showing that the system significantly reduced the average speed and increased speed limit compliance. Benekohal et al. (9) and Hajbabaie et al. (10) evaluated other speed control treatments in comparison to SPE, finding that Police plus speed feedback Trailer and SPE were in general the most effective in reducing mean speeds. They also presented some of the halo effects of SPE, after it departed the data collection location. In addition, Medina et al. (11) investigated the spatial effects (about 1.5 miles downstream of the treatment location) of SPE, Trailer, Police, and Police plus Trailer, finding that SPE consistently reduced the downstream speed of vehicles and that Police also had spatial effects but to a lesser degree.

Considering the effects of SPE on the speeds and headways simultaneously is important since it could reveal the effects of SPE on the overall safety at the construction site. If SPE reduces the speed of vehicles and does not reduce their headways, the net safety effects are positive as the probability of rear-end crashes is decreased. On the other hand, if SPE reduced the headway and does not reduce the speed it could potentially increase the probability of rear-end crashes by reducing the time available for drivers to react to the leaders.

Therefore, this study considers the effects of SPE on both speed and headways when used as a speed reduction treatment in highway work zones.

The remaining of the paper describes the data collection/reduction process, followed by the methodology to analyze data, findings, and lastly a summary of conclusions and closing remarks.

2. DATA COLLECTION/REDUCTION

The analysis presented in this paper is focused on a dataset collected during off-peak PM hours at a work zone located on I-55 in the State of Illinois, U.S.A, near the city of Joliet, a south western suburb of Chicago. The work area was located in the median (due to the addition of a third lane) and separated from the traffic by concrete barriers. In addition, bridge deck repair was taking place on I-55. Two lanes remained open to traffic with a normal-width right shoulder. The posted speed limit in the work zone was 55 mph, indicating a reduction of 10 mph compared to the 65 mph speed limit in normal conditions. The work zone was about 7 miles long, starting at milepost 255, and the treatments were deployed at milepost 259.

Data was collected using a video recorder and two markers that were placed outside of the roadway, as illustrated in Figure 2. It is noted that the video images were recorded at a location a few hundred feet downstream of the SPE van location, providing drivers enough travel distance to react and adjust their speed. In addition, the SPE van was placed in approximately straight highway sections and clear of obstacles, so that it was easily visible to approaching drivers from at least 500 ft upstream of the deployment location. Moreover, “Speed Photo Enforced” static signs were posted at the beginning of the work zone that was upstream of the SPE location. During data collection period, when the SPE van was present in the work zone, no ticket was issued and the officers were asked to do what they routinely did while they the SPE was parked in a highway except for issuing a ticket.

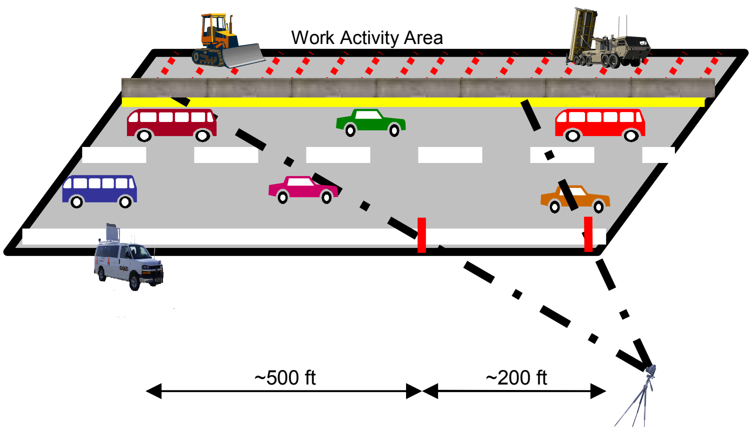


Figure 2. Schematic view of data collection setup

The recorded video images were time-stamped with a precision of 1/30 seconds (one stamp per video frame), thus it was possible to precisely determine the time every vehicle needed to travel the distance between the two markers, and consequently, to accurately calculate the speed. Additional information such as vehicle type (car or truck), traveling lane (shoulder lane or median lane), and free-flow or in-platoon traveling, was also collected. Free-flowing vehicles were defined as those who had the freedom to travel at their desired speed (they were not closely following another vehicle). A four-second headway criterion was used to distinguish free-flow from in-platoon vehicles.

Data was initially collected without the presence of the SPE van and used as a reference (or "base" data). Then, the data for the SPE van was collected at the same location, controlling for variables such as time of day and day of the week. Thus, all data to complete a full dataset was obtained at the same hours and during weekdays.

3. METHODOLOGY

The data analysis was conducted on multiple subgroups of the traffic stream based on the vehicle type (cars and trucks), the traveled lane (median and shoulder), and if the driver was traveling at his/her desired speed (or free-flow). Therefore, it was possible to determine the effects of each treatment on the different traffic subgroups and to perform more detailed comparisons than those obtained only for the whole traffic stream.

For the speed analysis, all vehicles traveling at free-flow condition were included in the analysis, whereas the general traffic stream was systematically sampled by measuring the speed of every fifth vehicle regardless of the vehicle type or the traveled lane. This random sampling is expected to provide an unbiased representation of the prevailing speeds of all traffic subgroups. For the headway analysis, on the other hand, all platooning vehicles were included.

The effect of the lead vehicle type on the headway of the followers should be considered in the headway analysis. The following four types of leaders and followers are defined:

1. A Car follows another Car: C→C,
2. A Truck follows a Car: T→C,
3. A Car follows a Truck: C→T, and
4. A Truck follows another Truck: T→T

The headway of a follower vehicle is the time elapsed since the front bumper of the lead vehicle crosses the marker until the front bumper of the follower crosses the same marker. Based on this definition, the length of the leader influences the value of the follower's headway. For example, for a certain travel speed, if two cars maintain the same (distance) gap from their leaders, the headway for a C→T pair is longer than the headway of a C→C pair. Thus, the effects of SPE on headways have to be studied on all of the different types of leaders and followers mentioned above and this analysis should be done for shoulder lane and median lane separately.

The effects of the treatments were evaluated based on changes in the mean speed, in the speed distribution, in the percentage of speeding drivers (for both excessive and moderate speeders), and in platooning headways.

The statistical significance of these changes was estimated using the following techniques: a) t-tests, to evaluate the changes in the mean speeds and platooning headways, and b) chi-square and kolomogorov-smirinov tests, to determine if the speed distributions for two different treatments were the same.

4. FINDINGS

4.1. Effects on the Mean Speed

This section presents the effects of the SPE in terms of changes in the traffic mean speed. Figure 3 shows the mean, minimum, and maximum speeds found for the general traffic

stream (sampled vehicles) and for free-flowing vehicles on I-55. It is noticed that the mean speeds were significantly reduced by the SPE. The mean speed in the base case (for general traffic stream) was above the 55 mph speed limit (58.8 mph). The SPE reduced the mean speed by 7.2 mph, bringing the mean speed down to 51.6 mph.
For free flowing vehicles, we observed similar speed reductions as the SPE van reduced the average speed of all free flowing vehicles by 6.7 mph bringing it down to 53.6 mph.

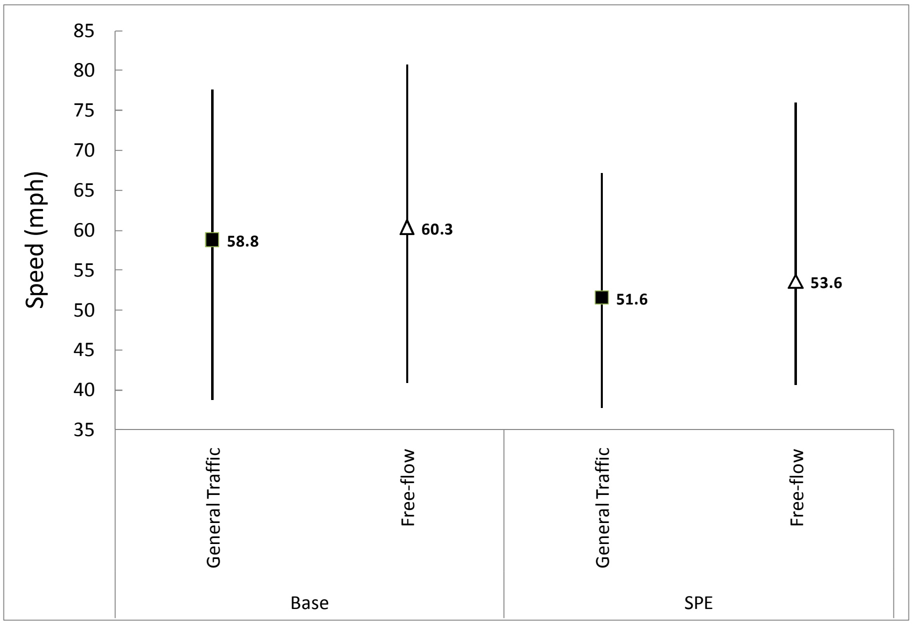


Figure 3. Average and range of mean speeds for the Base and the SPE cases.

The effects on the mean speed were also analyzed in more detail for each of the traffic subgroups. Table 1 shows the mean speeds for the two vehicle types (cars or trucks), the two travelled lanes (shoulder or median lanes), and for free flowing vehicles and the general traffic stream, as well as their statistical comparisons with respect to the base case. The SPE significantly reduced the speed of all subgroups. In addition, the mean speeds of cars were in general higher compared to trucks, as expected, and the speed reductions were also higher for cars than for trucks.

Table 1. Mean Speeds for the Base and the SPE cases.

Lane	Veh. Type	Treatment	Free Flow					General Traffic (Sampled Vehicles)				
			Sample Size	Mean Speed (mph)	Standard Deviation (mph)	Mean Reduction (mph)	Pvalue	Sample Size	Mean Speed (mph)	Standard Deviation (mph)	Mean Reduction (mph)	Pvalue
Median	Cars	Base	106	63.7	5.5	-	-	153	60.6	5.5	-	-
		SPE	102	55.9	5.4	7.8	<0.001	142	52.7	4.8	7.9	<0.001
	Trucks	Base	119	56.2	3.9	-	-	96	56.1	4.4	-	-
		SPE	99	52.3	3.5	3.9	<0.001	61	50.6	5.0	5.5	<0.001
Shoulder	Cars	Base	204	61.5	5.2	-	-	223	59.3	4.6	-	-
		SPE	219	53.6	4.3	7.8	<0.001	226	51.6	4.5	7.7	<0.001
	Trucks	Base	40	57.0	3.6	-	-	44	56.1	3.5	-	-
		SPE	43	51.2	4.2	5.8	<0.001	48	49.4	4.6	6.6	<0.001

Our findings in terms of speed reductions of SPE showed that the presence of the SPE in the I-55 work zone significantly reduced the mean speed of both free flowing vehicles and general traffic stream, and these reductions were significant for both vehicle types (car and trucks) and for both traveled lanes (median and shoulder lanes). This indicates that the SPE could potentially reduce the severity of rear-end collisions in the work zone.

4.2. Effects on the Speed distribution

As mentioned above, the general traffic stream was sampled by systematically selecting every fifth vehicle traveling through the data collection area. These individual speeds were also used to analyze the cumulative speed distributions and to determine the extent of the speed changes for vehicles traveling at higher speeds (e.g. at the 85th percentile) and lower speeds (e.g. at the 15th percentile).

Figure 3 shows the cumulative speed distribution of the general traffic stream in I-55 for the SPE and the base case.

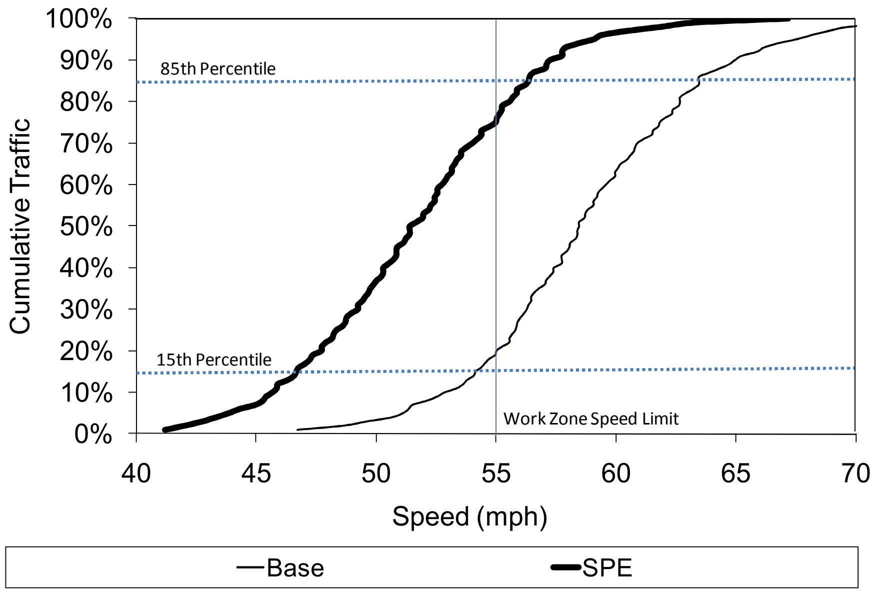


Figure 4. Speed distributions for the base and the SPE cases for general traffic stream.

When the SPE van was present in the work zone there was a clear shift of the whole distribution, at both low and high speeds towards lower speeds. Chi-square and Kolomogorov-Smirinov tests showed significantly different speed distributions when comparing the base case to the SPE case at 95% confidence level. The change in the speed distribution represented a change of -7.1 mph in the 85th percentile of the speed, and indicated that the SPE significantly lowered the number of speeding drivers and the severity of the speeding through the work zone.

4.3. Effects on the Speeding Drivers (Excessively and Moderately Speeding)

The effects of the SPE were also quantified based on the reduction of moderate speeders (speeding by 10 mph or less) and excessive speeders (speeding by more than 10 mph). Figure 5 shows the percentage of speeders and non-speeders for the general traffic stream and free flowing vehicles in I-55.

From Figure 5, it is observed that about 80% of the drivers in the base case were speeding, out of which 8.9% were excessive speeders. These percentages were greatly reduced by the SPE, lowering the speeders to about 25% and almost no excessive speeders (0.2%, corresponding to one vehicle).

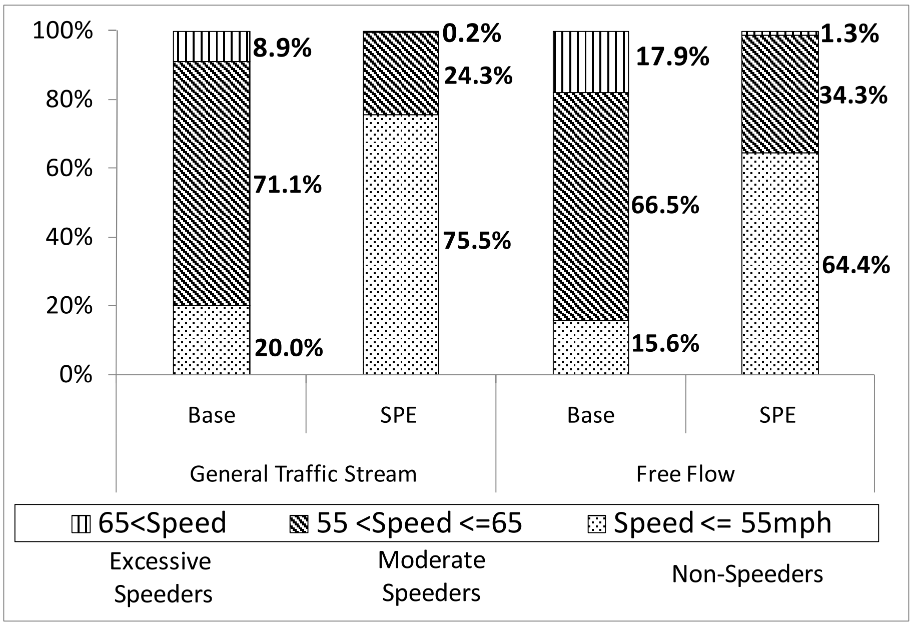


Figure 5. Degree of speeding for general traffic stream and free flowing vehicles.

A separate analysis based on free-flow vehicles also indicated significant effects in the frequency of speeding drivers and the degree of speeding for SPE. Specifically, it is highlighted that in the base case 17.9% of the drivers were excessive speeders, and this percentage was reduced to 1.3% with the SPE.

These figures indicate that the presence of the SPE van in the work zone greatly reduced the percentage of excessive speeders as well as moderate speeders in both free flowing vehicles and general traffic stream. This could potentially result in a decrease in the overall risks involved in excessive and moderate speeding.

4.4. Effects on the Average Headways of Platooning Vehicles

To determine if the SPE had a significant effect on the headway of vehicles at the deployment location, the average headway of all vehicles for the SPE case was compared to that for the Base case using student t-tests. As shown in Table 2, the average headway in the base case was 1.76 seconds while it was 1.79 seconds when the SPE was present in the work zone. This points out a slight numerical increase in the headway when the SPE was present in the work zone; however, the difference was not statistically significant as indicated by the P-value of 0.3907. This indicates that the presence of the SPE van in the work zone did not result in a reduction in the average headway of following vehicles in both lanes.

Table 2. Headway in Shoulder, Median, and Both lanes for the Base and the SPE cases.

Lane	Treatment	Sample size	Mean Headway (sec)	P-value
Both lanes	Base	1449	1.76	0.3907
	SPE	1354	1.79	
Shoulder	Base	746	1.76	0.3793
	SPE	657	1.79	
Median	Base	703	1.77	0.7439
	SPE	697	1.79	

At this point, it was clear that the SPE did not significantly reduce the average headway on any of the lanes when cars were combined with trucks. However, it was possible that SPE

had effects on the headway of some of the leader-follower pairs, thus the headway of the four individual pairs for the SPE case were compared separately.
As shown in Table 3, for all four different leader-follower pairs, the headway in the SPE case was not significantly different than that in the Base case. This observation was desired and showed that the SPE did not have negative effects on traffic headway at the deployment location. It should be noted that the sample size was not large enough to conduct the test for trucks in the shoulder lane since trucks were directed to drive in the median lane by a static sign.

Table 3. Average Headway for Different Leader – Follower Pairs.

Lane	Pair-type	Treatment	Sample size	Mean Headway (sec)	P-value
Shoulder	C→C	Base	624	1.70	0.4083
		SPE	568	1.74	
	C→T	Base	63	2.13	0.9112
		SPE	47	2.15	
	T→C	Base	54	1.96	0.4897
		SPE	36	2.10	
	T→T	Base	5	2.21	0.2709
		SPE	6	2.83	
Median	C→C	Base	429	1.52	0.2496
		SPE	355	1.46	
	C→T	Base	116	1.85	0.2902
		SPE	145	1.93	
	T→C	Base	71	2.33	0.2540
		SPE	101	2.17	
	T→T	Base	87	2.46	0.4925
		SPE	96	2.39	

CONCLUSIONS

In this study the effects of a Speed Photo-radar Enforcement system on the speed and headway of vehicles traveling trough a highway work zone were evaluated. Our findings showed that when the SPE van was present in the work zone the speed of general traffic stream and free-flowing vehicles was on average reduced by 7.2 mph and 6.7 mph, respectively. This brought the speed of general traffic stream and free-flowing vehicles down to 51.6 mph and 53.6 mph, respectively.
The presence of the SPE in the work zone significantly shifted the speed distribution towards lower speeds, and it reduced the percentage of excessive speeders (speeding by more than 10 mph) by 16.6% for free-flowing vehicles and by 8.7% for the general traffic stream.
At the same time that the SPE reduced the average speed of free flowing vehicles and the general traffic stream, it did not reduce the headway in the shoulder lane or in the median lane. In addition, an analysis of the headway of different leader-follower pairs (combinations of trucks and cars) revealed that the presence of the SPE in the work zone did not reduce the headway in any of these cases.
Based on the data from a work zone on I-55 in Illinois, U.S.A., it was found that the SPE has the potential to reduce the speed of traffic at the location it was implemented, while maintaining the headway between the vehicles.
This indicates that when SPE is present there is potential for drivers to travel slower and there is more time for them to react and maneuver to eventual changes in speed, which in

turn may decrease the probability and severity of rear-end collisions. As a result, the presence of the SPE van could improve the overall safety of highway work zones.

It is also noted that the deployment and operation of the SPE could offer some advantages over more traditional treatments since the police officers are not directly exposed to live traffic stream (they do not leave the van at any point). In addition, enforcement activities could be more effective with SPE because the process to issue a citation is continuous over time and the time to approve them is significantly shorter. However, the SPE system requires a support structure that includes legislation, training, and financial commitments from the governmental entities involved in the operation and safety of vehicular traffic.

The analysis of datasets collected at other locations is recommended for a comprehensive study of the effects of SPE in highway work zones under different traffic volumes and work zones configurations.

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