Monitoring Displays Coupled with Speed Cameras

Effectiveness on Speed Reduction

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Speeding is a common behavior of drivers all over the world. Traditional speed-controlling measures fail to reduce speeding effectively. With advances in technology, new devices have been developed for such a purpose, including a speed-monitoring display (SMD) that detects the speed of vehicles and displays it on an electronic board, informing drivers of their current speed. It has been hypothesized that SMDs coupled with speed cameras to catch violators may deter drivers from speeding. This study examined the effectiveness of SMDs with enforcement cameras on speed reduction. Speed data of free-flowing vehicles were collected before and after the SMD and enforcement cameras were installed. Speed data were also collected with the SMD turned off and then on again. The results showed that mean speeds of vehicles were significantly reduced after SMD and camera installation. Even with the SMD turned off, the speed reduction was not significantly affected, but the proportion of speeding vehicles became higher. It was found that the presence of SMDs could alert drivers of enforcement cameras downstream, making speeders adjust their speed to comply with the limit.

Road accidents often occur because of the failure of road users to abide by traffic rules. Although not all violations result in accidents, violators jeopardize the safety of other road users, a situation that can also lead to huge social costs. According to statistics of the National Police Agency, Taiwan, the largest proportion of traffic violations, over 31.71%, involve speeding (*1*). A speed survey conducted by the Department of Transport in the United Kingdom reported that 47% of cars were exceeding the 70-mph speed limit on motorways, 31% were breaking the speed limit in 40-mph zones, and 69% were breaking it on 30-mph roads. The FHWA indicated that on average, 70% of American drivers on Interstate highways exceed the 55-mph speed limit. In Sweden, the mean speeds are higher than the speed limit on almost all types of roads (*2*). Hence, speeding seems to be a common behavior among drivers around the world.

Generally speaking, driving at higher speed requires a longer braking distance and allows a shorter reaction time for drivers in case of emergency events. Severities of injuries and fatalities in accidents are related to the energy released by the vehicles in the collision, which is in direct proportion to the square of the speed. In other words, the higher are the driving speeds, the more severe the impact of collision and the higher the chances of injuries or fatalities will be. Driving speed is one of the determinants of the amount of risk to which drivers are exposed. Many studies have found evidence for the correlation between driving speed and likelihood as well as the severity of accidents. Cao et al. found that the enforcement of the 40-km/h bus speed limit had greatly improved road safety in Taipei (*3*). Hwang and Hwang reported that the severity of urban traffic accidents caused by speeding is 1.87 times that of accidents attributed to other causes (*4*). Taylor indicated that various measures of speed reduction were found to provide a substantial effect on accident frequency, and the increased number of accidents in the presence of speeders (those who drive faster than the speed limit) was particularly clear (*5*).

A speed limit, imposed on different types of roads or vehicles and different times of the year, is the most common way of controlling driving speed. However, its effectiveness in deterring speeding behavior is in question. In recent years, automatic speed enforcement with cameras has been widely adopted to compensate for the inefficiency of police enforcement. Research has also proved that automatic speed enforcement alerts speeding drivers to the higher chances of their being caught in action and thus serves as an effective deterrent to speeding. Elvik conducted a before–after study of the effects of a photo–radar program on collisions in Norway, controlling for general trend and regression to the mean (*6*). His study found a statistically significant 20% reduction in injury collisions. Further analysis revealed that the effect varied with the frequency of collisions at different sites. The higher are the number of collisions before the program, the greater the effect will be (*6*).

Chen et al. presented the results of an evaluation of the speed and traffic safety effects of the photo–radar program in British Columbia, Canada, after 1 year of full operation (*7*). Their study employed a number of analytical frameworks, including simple before-and-after comparison, time series cross-sectional analysis, and interrupted time series analysis. The results revealed a dramatic reduction in speed at photo–radar deployment sites. The reduction in speed was accompanied by a decrease in collisions, injuries, and fatalities. The analysis found a 25% reduction in daytime unsafe speed-related collisions, an 11% reduction in daytime traffic collision victims carried by ambulances, and a 17% reduction in daytime traffic collision fatalities (*7*).

A trial of hidden speed cameras began in mid-1997 in areas with 100-km/h speed limits in one of the four police regions in New Zealand. Keall et al. (*8*) evaluated the results of the first year of the trial. During that period, the hidden cameras and related publicity were found (compared with the generally highly visible speed camera enforcement in the rest of New Zealand) to be associated with net drops in speeds, crashes, and casualties both in speed camera areas

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and on roads with 100-km/h speed limits generally. There were initial changes in public attitudes in response to the program that later largely reverted to pretrial levels. Compared with the localized effect of visible cameras on speeds and crashes mainly in speed camera areas, the hidden cameras had a more general effect on all roads (*8*).

Apart from automatic speed enforcement, the speed-monitoring display (SMD) has also been adopted to deter speeding. It works by displaying the speed detected by radar to alert drivers when they are speeding. In other words, a SMD is a kind of feedback sign for preventing speeding. Feedback signs can be broadly categorized into two kinds: individual and collective. Individual feedback signs are displayed inside and outside the vehicle and include visual (words, speed, and license plate), auditory, and sensory messages, while collective feedback signs are messages indicating the percentage of drivers complying with the speed limit within a certain period of time (day or week) on a certain section of the road.

Blincoe et al. found that the deterred drivers' (those who have reduced their speeds since roadside cameras were installed) inadvertent speeding could be effectively targeted through improved and more frequent speed limit signs and reminder signs (*9*). This could simultaneously reduce a driver's accidental speeding and the anxiety associated with being unsure of the speed limit. Increased use of flashing signs could fulfill a similar function. These signs show the speed limit when they are activated by individual vehicles traveling above the specified speed (*9*).

Garber and Patel evaluated the effectiveness of variable message signs (VMSs) with a radar unit in reducing speeds at work zones (*10*). Four VMS messages designed to warn drivers that their speed exceeded the maximum safe speed were tested at seven work zones on two Interstate highways in Virginia. To assess the effect of the VMS with radar (on high-speed drivers in particular), vehicles that were traveling above a selected threshold speed triggered the radar-activated display and were videotaped as they passed through the work zones. The results indicated that the VMS with radar significantly reduced the speeds of speeding drivers. The messages used were rated according to their level of effectiveness, in the following order:

1. "You Are Speeding; Slow Down."
2. "High Speed; Slow Down."
3. "Reduce Speed in Work Zone."
4. "Excessive Speed; Slow Down." (*10*).

Vaa et al. conducted two experiments with a mobile roadside speedometer (*11*). The speed of each vehicle traveling in a specific direction was measured and shown immediately to the corresponding driver by means of a "neutral" display (one without flashing lights and without associations with enforcement or requirements) to urge drivers to slow down. Substantial reductions in average speeds were found for traffic being exposed to this speed feedback. In one of the experiments, with the provision of a previous warning sign (500 m before the speedometer), the permissible speed was reduced within a distance of at least 400 m (which was announced on the referred warning sign), reaching its greatest reduction at the speedometer site. There was neither speed reduction in the opposite direction (for which there was no feedback) nor significant time halo effects. In the other experiment (without previous warning signs), there were also no indications of time halo effects, the distance halo effect being estimated as long as 325 to 350 m; for traffic in the opposite direction (without speed feedback), some significant speed reductions were found (*11*).

Casey and Lund evaluated the effects of mobile roadside speedometers (a Doppler radar emitter and receiver to measure speeds and a display to indicate the speed of an approaching vehicle) as a means of controlling urban traffic speeds (*12*). The data indicate that generally the presence of speedometers reduced average traffic speeds by about 10% alongside the speedometer and about 7% at short distances downstream. The proportion of drivers exceeding the speed limit by at least 10% fell from 15% to 2% at one site on days the speedometer was deployed, and the device was particularly effective when deployed in school zones. However, the effect was limited to the times when it was actually deployed. Associated police enforcement in this study was clearly important in relation to the long-term effectiveness of roadside speedometers, as the effect appeared to last for about 3 weeks (*12*).

SMD coupled with police enforcement has been found to be effective in deterring speeders, but the effectiveness of SMD coupled with speed cameras has not been examined. To make up for this deficiency, this study assesses the effectiveness of SMD coupled with enforcement cameras on speed reduction and as deterrent to speeding behavior.

EXPERIMENTAL DESIGN

Research Site

The road section studied has two lanes each 3.5 m wide and a road shoulder 4.2 m wide in each direction. The road is separated by a center median. Northbound traffic was observed, and the specified speed limit was 50 km/h. Speed cameras were installed 150 m downstream from the SMD. The road section is fairly straight with a clear view.

Use of SMD

Figure 1 shows the stationary roadside SMD equipped with radar detection, with the speed limit of 50 km/h clearly visible in the center. To the right is the speed detected by the radar under the sign, "Your Speed XX km/hr," and to the left is the warning sign, "Speed Cameras Ahead. No Speeding," reminding drivers of the possibility of being caught speeding. The SMD can detect driving speeds of vehicles but not motorcycles or vehicles from the opposite direction.

The relative positions of the advance warning sign, SMD, and speed camera are as shown in Figure 2, which also indicates that, more than 500 m upstream from the SMD, the driver will first see the warning sign (Figure 3), with the specified speed limit (50 km/h) and the words, "Speed Cameras Ahead. Please Slow Down." The speed camera is installed 150 m downstream from the SMD (Figure 4).

Experimental Design

This experiment aimed to assess the effectiveness of the SMD on speed reduction, and observe the effect of the SMD—which provided visual feedback of current speed—on drivers' behavior. Experimental data were collected in four stages, and comparative analyses were conducted. The four stages were as follows:

Stage 1. Without SMD installed,
Stage 2. With SMD installed and turned on,
Stage 3. With SMD turned off, and
Stage 4. With SMD turned on again.

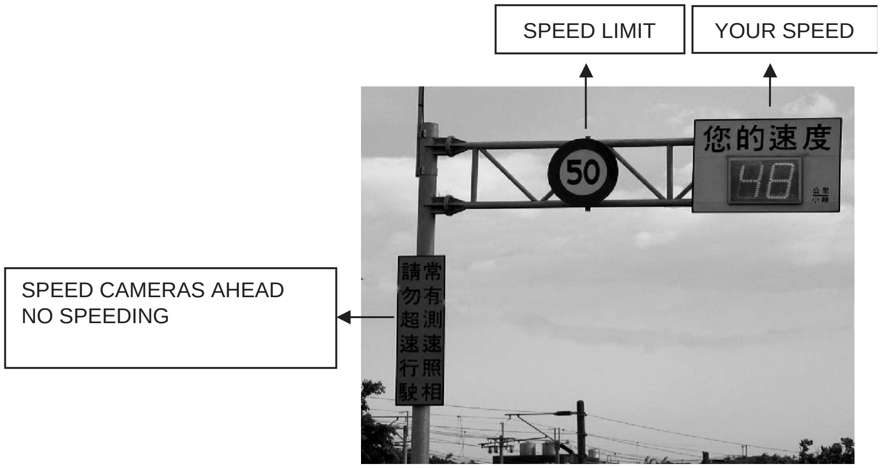

FIGURE 1 Speed monitoring display.

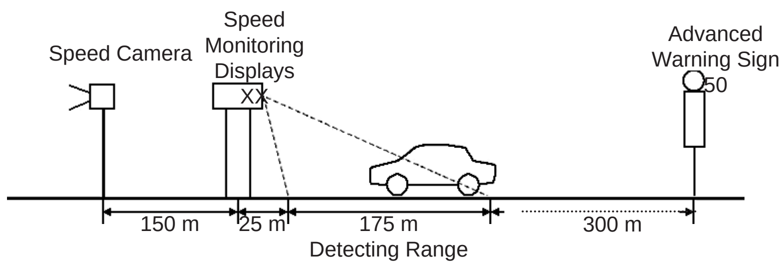

FIGURE 2 Relative positions of warning sign, SMD, and speed camera.

FIGURE 3 Warning sign.

FIGURE 4 Speed camera.

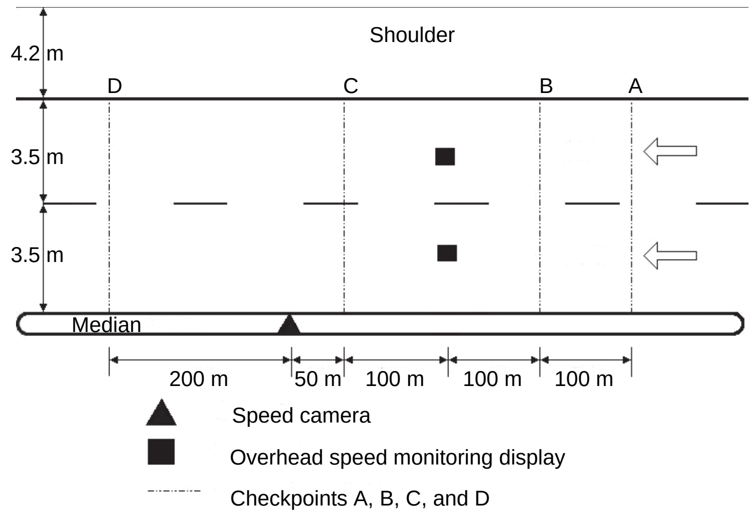

FIGURE 5 Positions of checkpoints for speed measurement.

Analysis results on data collected in Stages 1 and 2 can shed light on the effectiveness of the SMD on speed reduction while those on data collected in Stages 3 and 4 can reveal the impact of the SMD on driving behavior.

Figure 5 shows the four checkpoints where driving speed was measured. As the figure shows, Checkpoints A and B are 200 m and 100 m upstream from the SMD; Checkpoint C is 50 m upstream from the speed camera; and Checkpoint D is 200 m downstream from the speed camera. Before installation of the SMD (Stage 1), its exact location had not been decided; hence, only the speed at Checkpoint C was measured.

Haglund and Aberg have indicated that drivers' choice of speed could be influenced by other road users (*13*). To eliminate the impact of other road users, the targets of observation were drivers of free-flowing vehicles. To be included for analysis, a vehicle whose data were collected should have complied with the following criteria:

1. Vehicle to have been free flowing. According to McCoy et al., a vehicle is defined as free flowing if it has a headway exceeding 4 s (*14*). However, for convenience of field observation, the space that separates two vehicles traveling on the same route is better expressed in terms of distance. In this study, the road section observed had a speed limit of 50 km/h (i.e., 14 m/sec); hence, vehicles separated by headway exceeding 56 m were taken as free flowing.
2. Vehicle to have had no other vehicle within 56 m in adjacent lane. Vehicles running on the inside lane with no vehicles on the adjacent lane but with motorcycles running on the road shoulder were still considered free flowing.
3. Vehicle not to have changed lanes. Such behavior indicates the driver's intention to overtake or turn.
4. Vehicle to have had no police patrol in sight during data collection.

RESULTS AND DISCUSSION

A total of 833 data samples were collected.

Effect of SMD on Speed

From the mean speed data in Table 1, Figure 6 plots the changes in mean speed recorded at different checkpoints at different stages. As the figure shows, before the installation of the SMD (Stage 1), the mean speed was observed only at Checkpoint C and is represented by a point in the figure. Similar trends of changes in mean speed at the four checkpoints can be found for the other three stages.

Comparison of the mean speed at Checkpoint C for Stages 1 and 2 shows that there was a significant decrease in speed of 4.5 km/h after the SMD installation. However, there seemed to be little difference

TABLE 1 Mean Speed Recorded at Different Checkpoints at Different Stages

	A		B		C		D	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Stage 1. Without SMD	—	—	—	—	49.04 (103)	8.85	—	—
Stage 2. With SMD	55.07 (59)	7.13	54.15 (77)	8.03	44.53 (94)	6.98	52.42 (53)	8.38
Stage 3. SMD Off	54.21 (57)	7.06	54.07 (58)	7.85	45.06 (51)	9.63	54.58 (43)	6.25
Stage 4. SMD On	54.24 (60)	7.48	52.67 (64)	8.29	44.86 (58)	7.23	52.58 (56)	8.33

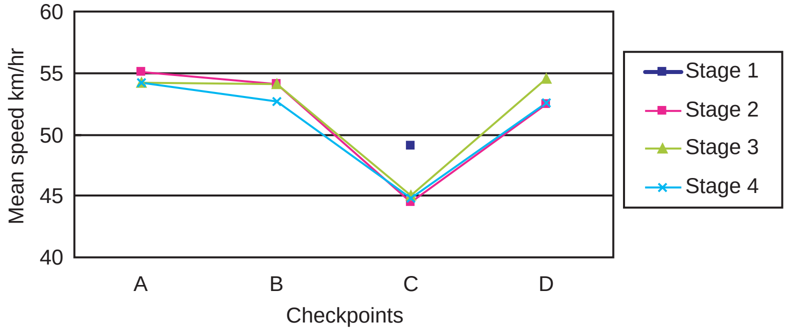

FIGURE 6 Changes in mean speed at different stages.

in speed between Stages 2, 3, and 4. Comparison of the mean speed at different checkpoints at the same stage reveals that the mean speed first dropped slightly between Checkpoints A and B, then dropped sharply between Checkpoints B and C, and rose again at Checkpoint D. The greatest speed difference was found between Checkpoints A and C, which on average reached 9.7 km/h.

To determine further the effect of SMD on vehicle speed, an analysis of variance (ANOVA) was performed on the speed data collected at different checkpoints and at different stages (Table 2). The results indicated that the differences in mean speed of vehicles at different stages were significant ($P < .01$), with the mean speed before SMD installation significantly higher than that at other stages. Scheffe's method with $\alpha = 0.05$ was also used to determine that the speed at Stage 1 was significantly different from the speed at the other three stages as a group.

Stage 1 Without SMD	*Stage 2 With SMD*	*Stage 3 SMD Off*	*Stage 4 SMD On*
49.04	44.53	45.06	44.86

As for Checkpoints A, B, and D, the ANOVA results for Stages 2, 3, and 4 did not reach the significance level. In other words, the mean speed of vehicles recorded at these three checkpoints at the three stages showed no significant difference.

The ANOVA results of mean speed of vehicles showed that the differences in mean speed of vehicles at the four checkpoints for Stages 2, 3, and 4 were significant ($P < .01$), with the mean speed at Checkpoint C significantly lower than that at other checkpoints. This result indicates that drivers will decelerate when approaching the speed camera (Checkpoint C) and then accelerate again further down the road; hence, the mean speed recorded at Checkpoint D was higher than at Checkpoint C and close to that at Checkpoints A and B.

TABLE 2 ANOVA Results of Mean Speed of Vehicles at Checkpoint C, Four Stages

	Sum of Squares	Degrees of Freedom	Mean Square	F	P
SSB	1,697.93	3	565.98	8.08	< 0.001*
SSE	21,153.99	302	70.05		
SST	22,851.92	305			

*Highly significant.

Table 3 shows the results of a paired *t*-test for mean speed of the same vehicle traced at Checkpoints B and C for Stages 3 and 4 grouped by a speed threshold of 50 km/h. As the table shows, the differences in mean speeds at these checkpoints were significant in both stages. That is, regardless of whether the speed of the vehicle was higher or lower than 50 km/h at Checkpoint B, the speed of the same vehicle at Checkpoint C still decreased.

Further investigation of the difference in speed of the same vehicle at Checkpoints B and C at Stages 3 and 4 showed that vehicles running above 50 km/h at Checkpoint B demonstrated a significant difference in speed for Stages 3 and 4 [$F(1, 58) = 9.52$; $P < .01$] but not for those running at 50 km/h or less at Checkpoint B [$F(1, 24) = 0.20$; $P = .66$]. The mean speeds recorded at the four checkpoints, except Checkpoint C, all exceeded the speed limit. That is, free-flowing vehicles tended to speed at the studied site. The comparison of differences at Checkpoint C found that the mean speed before SMD installation was significantly higher than that at other stages; this indicates that the installation of an SMD can help reduce speeds.

Effect of SMD on Speeding

As noted earlier, the road section under observation had a speed limit of 50 km/h. Someone driving above the limit, when caught, would be ticketed; and the higher that person's speed above the limit, the greater the fine that would be imposed. Table 4 shows the percentage of speeding at different checkpoints at different stages. Speeding at Checkpoint A was the most serious, with 76% of drivers exceeding the speed limit, though none drove faster than 70 km/h. In contrast,

TABLE 3 Results of Paired *t*-Test for Mean Speed at Checkpoints B and C

Mean Speed at Checkpoint B	t	Degrees of Freedom	P
Stage 3. SMD Off			
>50	6.23	23	<0.001*
≤50	5.81	12	<0.001*
Stage 4. SMD On			
>50	14.28	35	<0.001*
≤50	8.62	12	<0.001*

*Highly significant.

TABLE 4 Percentage of Speeding at Different Checkpoints at Different Stages

	Speed (km/hr)				
Stage	>50	>55	>60	>65	>70
Checkpoint A					
1	—	—	—	—	
2	76.27	40.68	32.20	11.86	0.00
3	77.27	31.82	27.27	9.09	0.00
4	76.80	30.46	29.58	11.32	2.06
Checkpoint B					
1	—	—	—	—	—
2	67.53	48.05	28.57	10.39	2.60
3	75.86	44.83	25.86	6.90	5.17
4	70.38	43.81	27.98	8.56	4.86
Checkpoint C					
1	34.95	17.48	12.62	5.83	2.91
2	24.47	6.38	2.13	0.00	0.00
3	27.45	15.69	9.80	1.96	1.96
4	26.60	8.51	3.19	0.00	0.00
Checkpoint D					
1	—	—	—	—	—
2	58.49	33.96	16.98	5.66	0.00
3	76.74	46.51	13.95	4.65	0.00
4	68.59	44.72	17.84	4.98	0.00

the ratio of speeding was the lowest at Checkpoint C, with only 35% of drivers speeding before SMD installation. The percentage of speeding was further reduced after the SMD was installed.

For Stages 2, 3, and 4, the percentage of speeding at Checkpoints A, B, and D showed no significant difference. In other words, with the SMD installed, the numbers of drivers exceeding the speed limit remained more or less the same. However, significant changes in the percentage of speeding were observed at Checkpoint C. As Figure 7 shows, there were more drivers speeding before SMD installation and fewer after SMD installation. There was a slight increase after the SMD was turned off, but the percentage of speeding decreased when the SMD was later turned on again.

In short, the greatest reduction in the percentage of speeding was found after the SMD was installed (Stage 2) and turned on again (Stage 4), followed by SMD being off (Stage 3). Although no significant difference in mean speed was observed with and without feedback signals (Stages 4 and 3, respectively), the provision of feedback on current speed helped decrease the percentage of speeding. Therefore, providing drivers the information on their current travel speed can serve as a warning, alerting them to decelerate and to comply with the speed limit.

CONCLUSIONS

From the results of the current study, the following conclusions are drawn:

1. After the SMD was installed, the mean speed recorded between the SMD and the speed camera was significantly reduced, by 4.5 km/h: installation of the SMD coupled with an enforcement camera helped reduce the driving speed in the road section observed.
2. There was a significant difference in mean speeds recorded between the SMD and the speed camera (Checkpoint C) and those recorded at 100 m (Checkpoint A) and 200 m (Checkpoint B) upstream from the SMD, as well as 200 m downstream from the SMD (Checkpoint D). These results reveal that the installation of an SMD had an effect on reducing the driving speed in the road section within the vicinity of the SMD.
3. For the same vehicle observed, whether the SMD was on or off and whether the vehicle's speed exceeded the limit or not, there was a reduction in mean speed recorded between the SMD and the speed camera (Checkpoint C), and the deceleration was more significant with the feedback signals provided and for speeding drivers.
4. Although there was no significant difference in mean speed observed with and without feedback signals, the percentage of speeding with the SMD on was lower than that with the SMD off. Providing drivers the information on their current travel speed alerted speeders of the need to decelerate. While such information was also available from the speedometer inside the vehicle, the SMD not only offered feedback on current speed, it also served to warn drivers of the enforcement camera downstream. Hence, as long as the SMD was installed, whether it was on or off, it exerted an influence on drivers' behavior. In sum, the SMD coupled with speed

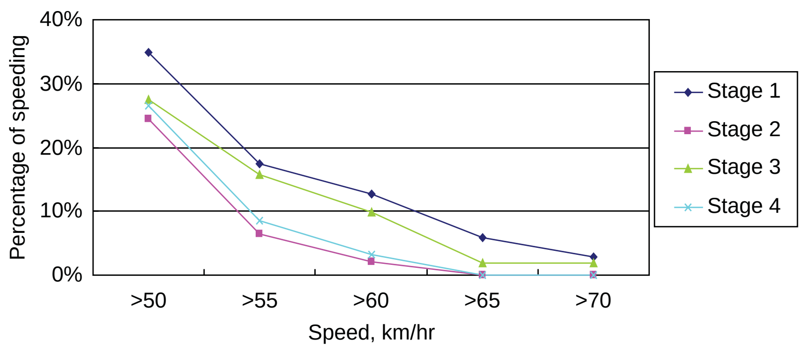

FIGURE 7 Percentage of speeding at Checkpoint C.

cameras was effective in reducing both speed and the percentage of speeding.

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