Speed Change Distribution of Vehicles in a Highway Work Zone

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In response to roadway geometry and traffic control devices, motorists may change their speeds within a work zone. Speed profile data for 102 automobiles (cars and vans) and 49 trucks, which traveled on a section of a traffic control zone 2.4 km (1.5 mi) long, were obtained. The average speeds of automobiles and trucks were 8 to 29 km/hr (5 to 18 mph) and 2 to 19 km/hr (1 to 12 mph), respectively, over the work zone speed limit. Vehicles decreased their speeds to the lowest level near the work space (Route 16 bridge). Even at the work space, about 65 percent of automobiles and 47 percent of trucks traveled faster than the speed limit. Automobiles and trucks reduced their speeds by 2 to 21 km/hr (3 to 13 mph) and 5 to 19 km/hr (3 to 12 mph), respectively, compared with their speeds at the beginning of the merging taper. As drivers traveled further into the traffic control zone their speeds first decreased, then slightly increased, and finally reached their minimum value at the work space. After passing it, the speeds continuously increased until vehicles left the study section. Comparisons of speed reductions at similar distances before and after the work space indicated that vehicles attempted to reach the speeds they had before the bridge. The speed reduction distributions for each vehicle group indicated that a small percentage of drivers reduced their speeds by large amounts. Thus, the speed reduction distribution plots were not bell shaped but had long tails (similar to lognormal or Pearson Type III distributions). Statistical analyses based on properties of a normal distribution would not be appropriate for interpretation of speed reduction data for most of the locations within a work zone.

Most drivers slow down when they perceive a potential hazard on the road, such as the presence of crew or large equipment near the traveled lane (*1*). However, the extent of speed reduction for an individual vehicle and the distribution of the reductions at different locations within a work zone are not known. This study was conducted to determine speed reduction distributions of vehicles at different locations within a temporary traffic control zone (work zone). The speed reduction study provides information that is not available from the previous studies (*2–7*), which measured speed at one or two points within the work zones.

The field experiment consisted of obtaining speeds of vehicles as they traveled through the construction zone. The vehicles were videotaped from the time they entered a study section 2.4 km (1.5 mi) long until they left it. A speed reduction profile for each vehicle was computed from the data. Speed reduction effects of various traffic control devices and roadway features may be examined using these data. The terminology suggested by Lewis (*8*) is used whenever possible to identify different locations in a traffic control zone (work zone). According to the terminology, a traffic control zone is divided into four areas—advance warning, transition, activity, and termination. The activity area is further divided into two spaces—buffer space and work space. The work space is only one small part of a work zone.

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STUDY APPROACH

The study approach is based on finding speed reduction profiles of vehicles in a construction zone and performing statistical analyses on the speed reduction effects of work zone roadway features and traffic control devices. The speed of a vehicle was monitored from the time it entered the study section until it exited from it. Two video cameras were used to collect data as vehicles traveled in the traffic control zone.

A vehicle was labeled as influenced if it was slowed down by another vehicle in front of it or exited from the ramp; otherwise it was labeled as uninfluenced. The uninfluenced vehicles were in free flow traffic traveling at their desired speeds in the traffic control zone. The findings of this study are based on the speed characteristics of the uninfluenced vehicles. The uninfluenced vehicles were divided into two vehicle groups—the automobile group and the truck group. The automobile group included passenger cars, vans, and pickup trucks. The vehicles in the truck group are of the tractor-semitrailer type.

Study Site Description

The construction zone was located on Interstate 57 near Mattoon, Illinois. The highway has two lanes per direction, but one lane in each direction was closed because of the construction. The traffic control zone was about 5.6 km (3.5 mi) long. The construction work was mainly repair of bridge decks over State Route 16 and another bridge about 4.0 km (2.5 mi) south of Route 16.

The speed limit inside the construction zone was 72 km/hr (45 mph) for all vehicles. Outside the work zone it was 105 km/hr (65 mph) for cars and 89 km/hr (55 mph) for heavy trucks. The traffic control plan (TCP) used in the work zone was one of the Illinois Department of Transportation's standard TCPs, which is prepared according to the guidelines given in the *Manual on Uniform Traffic Control Devices* (*9*). Figure 1 shows the signs used in this work zone.

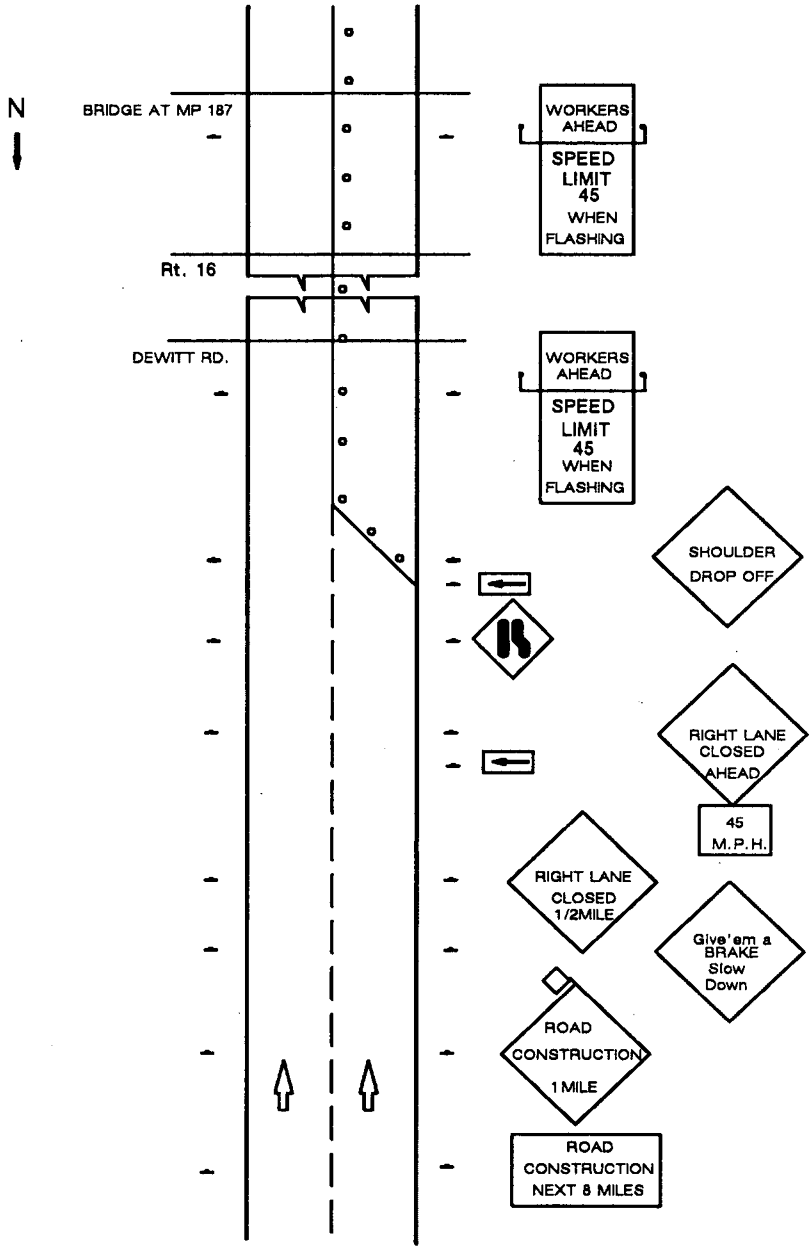


FIGURE 1 Work zone signs on SB I-57 during speed profile study.

Plan and Profile of Study Section

The plan and profile of the highway in the study section and the locations of speed measuring stations as well as the influence points are shown in Figure 2. The crest vertical curve, located in the middle of the study section, was approximately 854 m (2,800 ft) long. It started 122 m (400 ft) before the DeWitt Road overpass and ended 61 m (200 ft) before Route 16. There is a very short section with a 3 percent upgrade slope. The speed reduction due to the uphill section, if any, would be noticeable on the trucks but not on the cars (*10*).

Data Collection

Data were collected during weekdays and under normal weather conditions. Vehicles that were in free flow traffic in the beginning of the study section were videotaped to eliminate the effects of platooning. The average daily traffic on this section of the freeway was around 12,000 vehicles, with approximately 22 percent heavy commercial vehicles (*11*). A total of 208 vehicles were videotaped during the 3 days of data collection. Speed of a vehicle at a given point was computed on the basis of distance and time information. More details on speed calculation are given by Benekohal et al. (*12,13*).

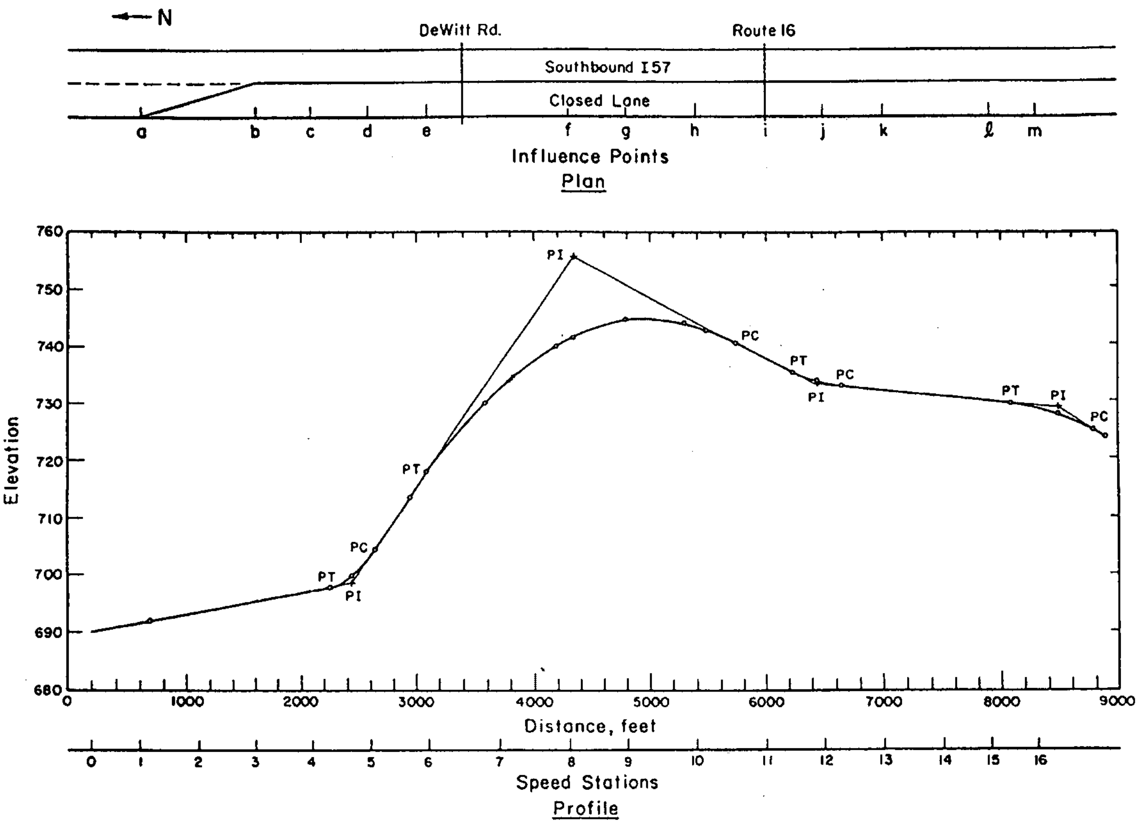


FIGURE 2 Plan, profile, and location of influence points and speed stations.

Data Reduction

Out of 208 vehicles, 57 were labeled influenced. The remaining 151 were labeled uninfluenced. The uninfluenced vehicles were divided into three vehicle types: passenger cars, tractor-semitrailer trucks, and vans and others (such as jeeps and pickup trucks). There were 74 cars, 49 trucks, and 28 vans and other vehicles in the uninfluenced group.

The speed characteristics of the car group were compared with those of the van group to determine whether there were significant differences for the two vehicle types. The results indicated that cars and vans had very similar speed characteristics. Thus, cars and vans were combined into one group, which is called automobiles. Therefore, the findings in this report are for two vehicle groups—the automobile group, which has 102 vehicles, and the truck group, which has 49 vehicles. For each vehicle, several sources of errors were identified, and their effects on speed were calculated. In general, the computed speed could be influenced by 1.6 km/hr (1 mph) or less because of these errors. Further details on data collection and data reduction are given by Benekohal et al. (*12,13*).

Influence Points

Throughout the construction zone, there are traffic control signs and roadway features that may influence the speed of a vehicle. An influence point (IP) is defined as a location within the construction zone that may have such a sign or roadway feature. Thirteen IPs, labeled *a* through *m*, were identified in this study. The IPs and their distances from the beginning of the study section are given in Table 1. The speed of a vehicle at these IPs was determined by using the speed profiles.

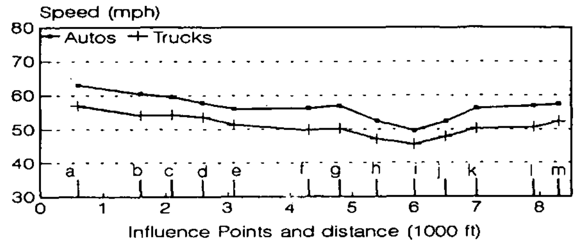
TABLE 1 Influence Points and Their Distances from the Beginning of the Study Section

INFLUENCE POINTS	LOCATION IN WORK ZONE	DISTANCE(ft)[a]
a	Beginning of the taper	600
b	End of the taper	1600
c	Before 1st speed limit signs	2100
d	At 1st speed limit signs	2600
e	After 1st speed limit signs	3100
f	Near the end of upgrade section	4300
g	1200 feet before Rt. 16 bridge	4800
h	600 feet before Rt. 16 bridge	5400
i	At Rt. 16 bridge (work space)	6000
j	500 feet after Rt. 16 bridge	6500
k	1000 feet after Rt. 16 bridge	7000
l	400 feet before 2nd speed limit signs	7900
m	Second speed limit signs and end of the study section	8300

[a] 1 foot = 0.305 meter (m)

Effects of Upgrade Slope on Speed

After the construction work was completed, adjustment data were collected to determine the speed reduction effects of the upgrade section. The mean speed reduction was 1.6 km/hr (1 mph) for cars and 8 km/hr (5 mph) for trucks. The speed change for most of the cars was concentrated between −1.6 and 3.2 km/hr (−1 and 2 mph), and for most of the trucks the concentration was between −4.8 and 9.7 km/hr (−3 and −6 mph) (*12*). It was not possible to separate the speed reduction effects of the traffic control devices (i.e., speed limit signs) from that of the upgrade on trucks.



1 foot = 0.305 meter (m)
1 mph = 1.61 kilometers per hour (km/h)

FIGURE 3 Average speed of vehicles at influence points in work zone.

OVERVIEW OF SPEED AND SPEEDING IN WORK ZONE

Speed Characteristics

At each IP, the maximum, minimum, average speed, and standard deviation of speed of automobiles and trucks were computed. These statistics are summarized in Table 2. Automobiles and trucks showed very similar speed characteristics in the study section. The mean speeds of trucks were about 6 to 11 km/hr (4 to 7 mph) lower than that of automobiles at all IPs. The mean speed profile for trucks is parallel to that of automobiles, as shown in Figure 3.

The construction zone over the bridge (work space) was delineated by portable concrete barriers (Jersey barriers). There were Jersey barriers over a length of about 76 m (250 ft). However, the open lane was wide enough [around 4.6 m (15 ft)] and did not give the feeling of going through a narrow lane. Although a previous study indicates that the concrete safety shape (Jersey) barriers do not affect highway capacity even when they are closer than 1.8 m (6 ft) to the traveled lane (*14*, p. 3-11), vehicles decreased their speed when they went through the work space. The main reason for the speed reduction seems to be the construction activities in the work space and the presence of the concrete shape barriers at this location.

Percentage of Automobiles Exceeding a Speed Level

The percentage of vehicles exceeding a given speed decreased over the bridge but increased to the same levels as before when drivers passed the bridge (see Figure 4). The percentage of automobiles exceeding a given speed at the second con-

TABLE 2 Speed Characteristics Statistics for Automobiles and Trucks (mph)

Influence Point	Minimum		Maximum		Mean		Std. Dev [a]	
	Auto	Truck	Auto	Truck	Auto	Truck	Auto	Truck
a	46.1	45.5	79.0	68.8	63.0	57.0	6.83	5.12
b	43.7	38.3	77.9	66.4	60.5	54.2	6.78	5.86
c	44.8	38.9	78.7	66.3	59.6	54.3	7.10	5.85
d	41.7	40.2	77.7	67.0	57.8	53.6	7.24	5.65
e	39.3	39.8	75.2	65.4	56.1	51.4	7.04	5.38
f	42.8	38.0	73.1	61.7	56.3	49.8	7.14	5.20
g	43.0	36.2	73.2	61.2	57.0	50.2	7.14	5.47
h	34.4	33.3	67.3	60.6	52.5	47.2	7.58	5.21
i	24.8	35.3	67.2	59.7	49.6	45.5	9.48	5.13
j	29.8	36.8	68.1	62.5	52.4	47.9	8.35	5.31
k	41.2	42.1	68.7	62.4	56.2	50.2	6.11	4.75
l	44.7	41.9	69.3	62.1	57.0	50.7	5.94	4.76
m	41.8	40.5	72.8	64.8	57.4	52.3	6.73	5.19

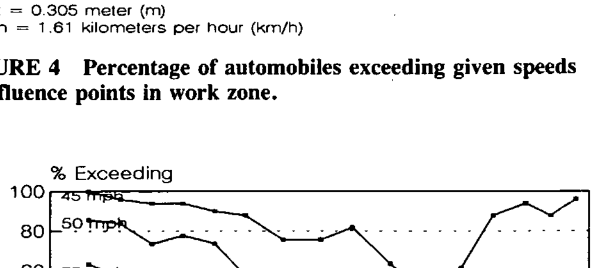
[a]Std. Dev = Standard Deviation
1 mph = 1.61 km/h

struction zone speed limit signs (IP *m*) almost reached the level of the first speed limit signs (IP *d*). This indicates that, on the average, the drivers decreased their speeds to the lowest level near the work space, but after passing it they accelerated to the same speeds they had at the first speed limit signs.

The percentage of automobiles exceeding the speed limit over the bridge (IP *i*) was the lowest compared with other locations; however, nearly 65 percent of automobiles traveled faster than 72 km/hr (45 mph) at this location. The curves in Figure 4 are roughly parallel to each other and appear to be in a W shape. The shape indicates that the drivers increased their speeds after passing the first speed limit signs (IP *d*) and before arriving at the bridge (IP *i*). There was 1037 m (3,400 ft) between IP *d* and IP *i*. The drivers may have perceived this distance to be too long, so they increased their speed.

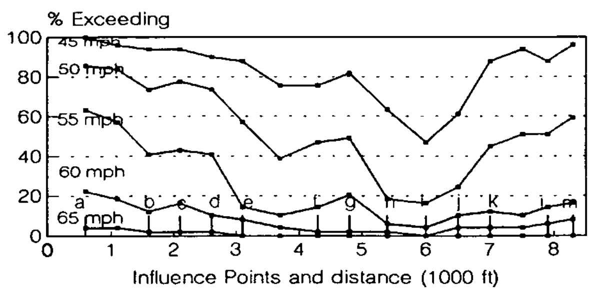
Percentage of Trucks Exceeding a Speed Level

The percentages of trucks exceeding a given speed at different locations within the study section are shown in Figure 5. The percentage of trucks exceeding a given speed decreased over the bridge and increased, in general, to the same levels as before the bridge. The percentages of trucks exceeding a given speed at the first and second work zone speed limit signs (IP *d* and IP *m*) are almost equal. The percentage exceeding curves appear to be parallel and have a W shape. There were more drivers exceeding a given speed at the first speed limit sign than at the bridge. At the bridge, 47 percent of trucks traveled faster than 72 km/hr (45 mph).



1 foot = 0.305 meter (m)
1 mph = 1.61 kilometers per hour (km/h)

FIGURE 4 Percentage of automobiles exceeding given speeds at influence points in work zone.



1 foot = 0.305 meter (m)
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FIGURE 5 Percentage of trucks exceeding given speeds at influence points in work zone.

SPEED REDUCTIONS AT INFLUENCE POINTS

In this section the distribution of speed differences rather than the difference of the average speeds is used to examine relative effects of roadway features and traffic control devices on speeds of vehicles. The speed reduction distribution provides more insight into drivers' responses than the difference of average speeds. To find the distribution, the speed difference at a given IP compared with a reference IP was computed for each vehicle. The speeds at all IPs were compared with the speeds at the first IP (IP *a*). In addition, speeds at selected pairs of IPs were compared with each other.

Paired *t*-tests were used to compare the speed differences between pairs of IPs. In a paired *t*-test, for a given pair of IPs, the mean of speed differences rather than the difference of the mean speeds is used to make statistical inferences. The results from the paired *t*-test analysis would help to examine how roadway features and traffic control devices affected the speed of vehicles and whether the effects were statistically significant.

Reductions Compared with Speed at the Beginning

Speed Change Statistics

Summaries of speed changes are given in Tables 3 and 4. The average speed reductions varied from 4.0 km/hr (2.5 mph) to 21.6 km/hr (13.4 mph) for automobiles and from 4.2 km/hr (2.6 mph) to 18.5 km/hr (11.5 mph) for trucks. As drivers traveled further into the traffic control zone, the reduction first increased, then slightly decreased, and finally reached its maximum value at the bridge. Beyond the bridge, the speed reductions continuously decreased until vehicles exited the study section. The standard deviations given in Tables 3 and 4 reflect the degree of the concentration of the speed reductions.

Instead of speed change confidence intervals, observed ranges for 90 percent of the speed changes at each IP are presented in Tables 3 and 4. Since most of the speed reductions were not normally distributed, the method of finding the confidence interval for the normal distribution should not be used here. For example, if the speed reduction had been normally distributed for automobiles at IP *f*, 90 percent of speed reductions would have been within 26.9 and −5.3 km/hr (16.7 and −3.3 mph). However, 90 percent of the observed speed reductions were within −29.6 and −1.1 km/hr (−18.4 and −0.7 mph). This example illustrates the importance of knowing the distribution of the differences to avoid an error in interpretation of the speed reduction data.

Speed Reduction Distributions

The speed reduction distributions for automobiles and trucks are given in Figure 6. Almost all of the frequency plots show a small percentage of drivers who reduced their speeds by a

TABLE 3 Average of Individual Vehicle Speed Changes Between Pairs of Influence Points for Automobiles (mph)

Influence Points Compared	Average Speed Differences	Standard Deviation	Standard Error	Confidence Level Speeds Are Different	Observed Range for 90% of Speed Changes	
					Lower Limit	Upper Limit
(IP b)-(IP a)	-2.5	2.80	0.28	99.99	-8.5	0.7
(IP c)-(IP a)	-3.4	3.76	0.37	99.99	-10.3	0.4
(IP d)-(IP a)	-5.2	4.67	0.46	99.99	-15.4	0.4
(IP e)-(IP a)	-6.9	5.21	0.52	99.99	-15.8	-1.1
(IP f)-(IP a)	-6.7	6.08	0.60	99.99	-18.4	0.7
(IP g)-(IP a)	-6.0	6.42	0.64	99.99	-18.4	2.5
(IP h)-(IP a)	-10.5	7.32	0.72	99.99	-23.8	-0.2
(IP i)-(IP a)	-13.4	9.02	0.89	99.99	-29.1	-0.5
(IP j)-(IP a)	-10.6	7.82	0.77	99.99	-25.1	-0.7
(IP k)-(IP a)	-6.8	6.02	0.60	99.99	-17.2	1.2
(IP l)-(IP a)	-6.0	5.49	0.54	99.99	-15.8	1.3
(IP m)-(IP a)	-5.6	6.14	0.61	99.99	-16.3	3.0
(IP h)-(IP j)	0.04	4.47	0.44	6.76	-5.7	7.9
(IP c)-(IP e)	3.5	3.56	0.35	99.99	-1.0	10.8
(IP d)-(IP m)	0.4	5.42	0.54	50.21	-7.8	10.2
(IP g)-(IP k)	0.9	4.37	0.43	94.83	-5.5	9.8

1 mph = 1.61 km/h

large amount. These drivers are represented by the left tail of the frequency curves.

The frequency distributions are not bell shaped. Most of the speed reduction distributions have a long tail, and they are similar to lognormal or Pearson Type III distributions. These shapes must be considered in interpreting speed reduction data. For example, the average speed reduction of automobiles at the end of the taper was 4.0 km/hr (2.5 mph). This indicates that automobile drivers reduced their speeds, on the average, by 4.0 km/hr (2.5 mph) when they reached the end of the taper. However, the speed reduction frequency distribution for IP *b* shows that 33 percent of automobiles reduced their speeds less than 1.6 km/hr (1 mph), and 53 percent of them reduced less than 3.2 km/hr (2 mph) between the beginning and end of the taper. Thus, the average speed reduction is greatly influenced by the 47 percent of automobiles that had reductions larger than 3.2 km/hr (2 mph). Similar arguments can be made for IP *c* and IP *d*.

Similarly, for trucks the average speed reduction at the end of the taper was 4.3 km/hr (2.7 mph). Nevertheless, nearly 22 percent of trucks reduced their speeds less than 1.6 km/hr (1 mph), and 47 percent of them reduced speed by less than 3.2 km/hr (2 mph) between the beginning and end of the taper. Thus, the remaining 53 percent significantly influenced the average speed reduction value. A similar analysis can be made for IP *c* and IP *d*.

TABLE 4 Average of Individual Vehicle Speed Changes Between Pairs of Influence Points for Trucks (mph)

Influence Points Compared	Average Speed Difference	Standard Deviation	Standard Error	Confidence Level Speeds Are Different	Observed Range for 90% of Speed Changes	
					lower Limit	Upper Limit
(IP b)-(IP a)	-2.7	2.14	0.31	99.99	-5.8	0.8
(IP c)-(IP a)	-2.6	2.47	0.35	99.99	-6.5	0.6
(IP d)-(IP a)	-3.4	2.76	0.39	99.99	-7.3	0.6
(IP e)-(IP a)	-5.6	3.20	0.46	99.99	-10.7	-1.4
(IP f)-(IP a)	-7.2	4.22	0.60	99.99	-15.5	-1.2
(IP g)-(IP a)	-6.7	4.78	0.68	99.99	-15.2	-0.3
(IP h)-(IP a)	-9.8	5.24	0.75	99.99	-18.8	-2.2
(IP i)-(IP a)	-11.5	6.03	0.86	99.99	-22.0	-2.2
(IP j)-(IP a)	-9.1	6.09	0.87	99.99	-19.2	-0.3
(IP k)-(IP a)	-6.7	5.21	0.74	99.99	-14.7	0.4
(IP l)-(IP a)	-6.3	4.69	0.67	99.99	-12.3	1.1
(IP m)-(IP a)	-4.7	5.00	0.71	99.99	-11.9	3.1
(IP h)-(IP j)	-0.7	3.44	0.49	82.55	-4.9	5.4
(IP c)-(IP e)	3.0	2.48	0.35	99.99	-0.1	6.5
(IP d)-(IP m)	1.3	4.24	0.61	96.61	-5.3	7.9
(IP g)-(IP k)	0.01	3.73	0.53	1.58	-6.2	6.5

1 mph = 1.61 km/h

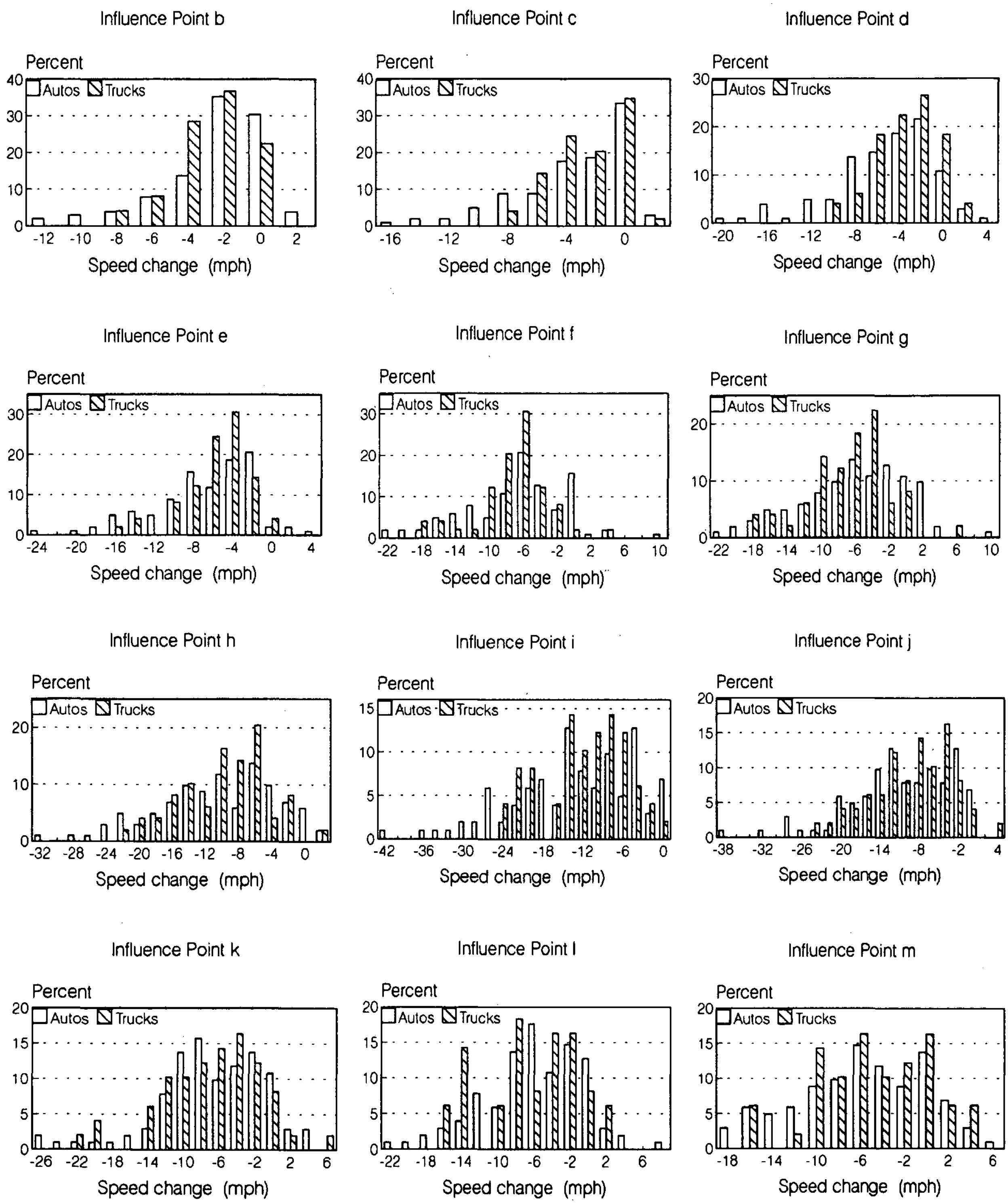
Normality Test for Automobiles and Trucks

As mentioned earlier, it is noticeable that not all of the speed reduction distributions were bell shaped. The distributions around the bridge are closer to a normal distribution than those of the other points. Statistical tests are needed to determine which distributions are normal. The method used here is the Shapiro-Wilk's statistic for normality testing (*15*). In this method, the Shapiro-Wilk statistic, W, which is the ratio of the best estimator of the variance (based on the square of a linear combination of the order statistics) to the usual corrected sum of squares estimator of the variance, is computed, where $W > 0$ and $W \leq 1$. Smaller values of W lead to rejection of the null hypothesis that the distributions are normal (*15*). Table 5 gives the normality test results for the distributions shown in Figure 6.

Speed reduction distributions for automobiles at all IPs are not normally distributed with a 90 percent confidence level (Table 5). Similarly, the speed reduction distributions for trucks are not normally distributed except at four locations near the bridge. These four IPs are located at 366 m (1,200 ft) and 183 m (600 ft) before the bridge and 153 m (500 ft) and 305 m (1,000 ft) after the bridge.

Speed Change Profile for Automobiles

The speed change profile and observed ranges for 90 percent of the speed changes for automobiles are given in Table 3.



1 mph = 1.61 kilometers per hour (km/h)

FIGURE 6 Distribution of speed changes at Influence Points *b* through *m* compared with Influence Point *a*.

TABLE 5 Shapiro-Wilk's Normality Test Results and Interpretation of Them with 90 percent Confidence Level

Influence Point	Auto		Truck	
	Prob<W	Normal	Prob<W	Normal
IP b	0.0001	No	0.0001	No
IP c	0.0001	No	0.0001	No
IP d	0.0001	No	0.0179	No
IP e	0.0001	No	0.0050	No
IP f	0.0184	No	0.0068	No
IP g	0.0393	No	0.1875	Yes
IP h	0.0098	No	0.2799	Yes
IP i	0.0006	No	0.0857	No
IP j	0.0001	No	0.3254	Yes
IP k	0.0001	No	0.7761	Yes
IP l	0.0905	No	0.0313	No
IP m	0.0735	No	0.0549	No

Automobile drivers displayed, on the average, a 4.0-km/hr (2.5-mph) speed reduction at the end of the taper compared with the beginning of it. They continued reducing their speeds after passing the taper. At the first speed limit signs (IP *d*), the mean speed reduction was about 8 km/hr (5 mph). The reduction fluctuated between 10 and 11 km/hr (6 and 7 mph) until the vehicles reached IP *h*. At IP *h*, which is about 183 m (600 ft) before the bridge, the reduction increased to 16.9 km/hr (10.5 mph). The maximum average speed reduction was 21.6 km/hr (13.4 mph), which occurred over the bridge (IP *i*). The maximum speed reduction for automobiles was 67.5 km/hr (41.9 mph), which also happened at the bridge. The standard deviation of speed differences increased as automobiles approached the work space, and the largest one [14.52 km/hr (9.02 mph)] occurred at IP *i*.

After passing the bridge, the speed reductions became smaller as drivers traveled further away from the bridge. The reductions on either side of the bridge are very similar, indicating that the drivers, after passing the bridge, almost reached the speeds they had before the bridge.

Speed Change Profile for Trucks

Trucks showed speed reduction patterns (Table 4) similar to those of automobiles. The largest average speed reduction was 18.5 km/hr (11.5 mph), which occurred over the bridge (IP *i*). The maximum speed reduction for trucks was 39.1 km/hr (24.3 mph), which also happened at the bridge. The standard deviation of speed differences increased as trucks approached the work space, and the largest ones, 9.71 and 9.80 km/hr (6.03 and 6.09 mph), occurred at IP *i* and IP *j*. After passing the bridge, truck drivers also increased their speeds even though there was another pair of speed limit signs ahead. And the reductions on either side of the bridge are very similar. This means that after passing the work space, the drivers almost reached the speed they had before it.

Reductions Compared with Other Points

Automobiles

Further comparisons between pairs of IPs were made (Table 3). The first pair to be considered were the points 183 m (600 ft) before and 153 m (500 ft) after the bridge (IP *h* versus IP *j*). For this pair, the speed difference for automobiles was 0.06 km/hr (0.04 mph), indicating that the speeds at these points were not significantly different. This means that the drivers reduced their speeds over the bridge but increased them to the same level as before the work space.

The second pair of IPs compared were the points 153 m (500 ft) before and 153 m (500 ft) after the first speed limit signs (IP *c* versus IP *e*). The mean speed reduction was 5.6 km/hr (3.5 mph), which is a significant reduction. This means that on the average the speed was reduced 5.6 km/hr (3.5 mph) around the first speed limit signs. Assuming that at 153 m (500 ft) before the first speed limit signs the drivers had reached their desired speed, the mean speed difference of 5.6 km/hr (3.5 mph) is mainly caused by the speed limit signs.

Thus, one may conclude that the speed limit signs were effective in reducing the average speed of automobiles by 5.6 km/hr (3.5 mph) at a point immediately after the signs. The adjustment data showed that the mean speed reduction for automobiles caused by the upgrade segment would be less than 1.6 km/hr (1 mph) for the 305-m (1,000-ft) travel distance.

The third comparison was between IP *d* and IP *m*, where the first speed limit signs and the second speed limit signs were located. The difference in reductions between these two IPs was 0.6 km/hr (0.4 mph), which was not significant. This indicates that automobiles drove at similar speeds at these two points.

The last comparison pair was IP *g* and IP *k*, 366 m (1,200 ft) before and 305 m (1,000 ft) after the bridge. The reduction difference between them was 1.4 km/hr (0.9 mph). This indicates that after traveling about 305 m (1,000 ft) past the bridge, vehicles attempted to reach the speed they had 366 m (1,200 ft) before the bridge.

Trucks

As for automobiles, further comparisons were made between pairs of IPs to assess the reductions at selected points (Table 4). The same IPs were selected for trucks as for automobiles. First to be considered were the points 183 m (600 ft) before and 153 m (500 ft) after the bridge (IP *h* versus IP *j*). For this pair, the speed difference for trucks was 1.1 km/hr (0.7 mph), indicating that the average speed of trucks 366 m (600 ft) before the bridge was not significantly different from that 153 m (500 ft) after the bridge. This means that the drivers reduced their speed over the bridge but increased it to the same level as before the work space.

The second comparison was between the points 153 m (500 ft) before and 153 m (500 ft) after the first speed limit signs (IP *c* versus IP *e*). The mean speed reduction for this pair was

4.8 km/hr (3.0 mph), a significant amount. This means that on the average the speed was reduced by 4.8 km/hr (3.0 mph) around the first speed limit signs. Assuming that at 153 m (500 ft) before the first speed limit signs the drivers had reached their desired speeds, the mean speed difference of 4.8 km/hr (3.0 mph) is mainly caused by the speed limit signs. A portion of this reduction may be due to the upgrade segment on the highway, but that portion cannot be determined from the available data. Thus, considering the upgrade effect, it can be concluded that the trucks on the average reduced their speeds by less than 4.8 km/hr (3 mph) immediately after passing the speed limit signs.

The third comparison was between IP *d* and IP *m*, where the first speed limit signs and the second speed limit signs were located. The difference in reductions between these two IPs was 2.1 km/hr (1.3 mph), which was not significant. This indicates that although the trucks reduced their speeds over the bridge, by the time they reached IP *m* they increased their speeds to the speed level they had at IP *d*.

The last comparison pair was IP *g* and IP *k*, 366 m (1,200 ft) before and 305 m (1,000 ft) after the bridge. The reduction difference between them was 0.02 km/hr (0.01 mph). This indicates that after traveling about 305 m (1,000 ft), vehicles attempted to reach the speed they had 366 m (1,200 ft) before the bridge.

CONCLUSIONS

Automobiles and trucks decreased their speeds to the lowest level near the work space, but after passing it they increased their speeds to the higher levels they had before the work space. The percentage of vehicles exceeding a speed level decreased as they approached the work space (bridge), but after passing the work space the percentage increased to the higher levels found before the work space. Even at the work space nearly 65 percent of automobiles and 47 percent of trucks were speeding.

Automobiles and trucks, on the average, traveled 5 to 21 km/hr (3 to 13 mph) and 5 to 19 km/hr (3 to 12 mph), respectively, slower inside the traffic control zone compared with their speeds at the beginning of the merging taper. As drivers traveled further into the traffic control zone, the speed reductions first increased, then slightly decreased, and finally reached a maximum value at the bridge. Beyond the bridge, the speed reductions continuously decreased until vehicles left the study section.

A small percentage of drivers reduced their speeds by large amounts; thus, the mean speed is influenced by these large reductions. The speed reduction frequency distribution plots were not bell shaped at most locations but had a long tail (similar to lognormal or Pearson Type III distributions).

Comparisons of speed reductions at similar distances before and after the work space indicated that vehicles attempted to reach the speeds they had before the bridge. The speed reductions before and after the first work zone speed limit signs were also compared. The speed limit signs were found to be effective in reducing the average speed of automobiles by 5.6 km/hr (3.5 mph) and that of trucks by less than 4.8 km/hr (3.0 mph) at a point immediately after the signs.

RECOMMENDATIONS

The locations at which drivers slow down or speed up are critical points in a construction zone. Knowing these points would help in placing the signs at appropriate locations. It is recommended that the placement and frequency of the work zone speed limit signs be examined using the speed reduction pattern of the vehicles. The location of the signs and the length of the section before the work space should be such that most drivers are encouraged to follow the speed limit.

The analysis indicated that location of a speed-measuring station has to be carefully selected because it will affect the outcome of the measurements. Furthermore, speed distributions, as well as the mean speeds, should be analyzed to obtain more accurate speed characteristic data. Speed profile data from other work zones should be used to further validate the findings of this study.

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