DRIVER RESPONSE TO THE 55-MPH MAXIMUM SPEED LIMIT AND VARIATIONAL CHARACTERISTICS OF SPOT SPEEDS

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ABRIDGMENT

Spot speed observations were made on a four-lane suburban freeway from November 8, 1973, to June 13, 1974, when speeds were influenced by fuel conservation measures. Speeds were recorded in 15-min intervals in mid-afternoons on 39 days. The mean speed of cars dropped from 63.4 mph (102 km/h) in early November to 60.4 mph (97.2 km/h) in late November to early March and was further reduced to 57.4 mph (92.4 km/h) after the posted speed limit was changed from 70 to 55 mph (113 to 88 km/h) on March 3, 1974. A multiple classification analysis of the 15-min mean speeds showed that the variance of these means was not significantly affected by factors such as time of day, day of the week, traffic flow, and truck composition, although an effect due to different observers was found. The residual variance of the 15-min means after systematic effects were removed was significantly greater than would be expected from sampling errors if the speeds of individual cars were identically distributed. The implications of these results with respect to the planning and design of before and after speed studies are discussed.

•THE RECENT introduction of a 55-mph (88-km/h) nationwide speed limit as a fuel conservation measure offered an unprecedented opportunity for studying driver responses to changes in maximum speed limit laws.

The fuel situation was brought to public attention by the President's televised speech on November 7, 1973. Since then, the public has been urged to reduce fuel consumption through various voluntary and regulatory measures, including speed reductions. Since March 3, 1974, speed reductions have been made mandatory nationwide through the imposition of 55-mph (88-km/h) maximum speed limits.

To observe the driving public's response to the speed limit change, we made a series of spot speed observations at a suburban freeway in the Detroit metropolitan area where the speed limit had been 70 mph (113 km/h). A number of studies have been made to determine the effect of the new speed limit (1, 2). One aim of the present study was to obtain information on the detailed characteristics of driver response in a more or less continuous manner over a relatively long time span. Hence, observations were made several times a week during periods immediately before and after the new speed limit took effect and at less frequent intervals in other periods from early November 1973 to November 1974.

This extensive series of speed measurements is also of interest from a more fundamental point of view. As a second aspect of this study, a statistical analysis has been made of the variational characteristics of observed mean speeds in 15-min periods. Attempts were made to relate the variations to characteristics of the traffic stream, such as the total volume and the number of trucks, and observational conditions, such as

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the time of day, day of the week, and observer. The results of the analysis are important for the planning and design of spot speed studies.

DATA COLLECTION

Speed observations were made on Mich-59, a four-lane freeway in a suburban setting about 20 miles (30 km) north of Detroit, where influences of curves, grades, and nearby exits or entrances were judged to be minimal. All observations were made in good weather on weekday afternoons between 1:40 and 3:50 p.m. The traffic flow was generally between 200 and 450 vehicles per lane per hour, including about 10 percent trucks. New speed signs were posted on this road by March 4, 1974, the day after the law became effective.

Speeds of individual vehicles were recorded in 15-min intervals for the westbound traffic by using a radar speed meter located off the freeway right-of-way. The entire data system was calibrated and checked in the field by recording the speed of a test vehicle with a calibrated speedometer. Individual speeds could be measured to a precision of ±1.0 mph (±1.6 km/h). Trucks were separated from light-duty vehicles. It was not always possible to single out the speeds of individual vehicles when bunches of vehicles passed through the radar beam, but this was not an important factor under the prevailing light flow. On a typical day, observations were made during six 15-min intervals and about 800 individual speeds were recorded.

The first measurements were made on November 8 and 9, 1973, the days immediately following the President's first televised speech on the energy situation. Additional measurements were made at irregular intervals in November and December 1973, and January and early February 1974. More frequent measurements were made in late February and in March in order to provide a detailed picture of driver response during the period immediately before and after the Michigan statutory speed limit went into effect on March 3. State police enforcement of the new law began on March 16, 1974. Since April 1974 observations have been continued on a less frequent basis. All together, 259 observations in 15-min intervals were made on 46 days.

In July 1974, the observation point had to be moved about 1 mile (1.6 km) downstream because of roadside developments. Observed speeds at the new site were about 1.1 mph (1.8 km/h) higher than at the previous site. Because this effect may be due to the new site, these data have not been included in the statistical analysis discussed below.

DRIVER RESPONSES

The results of the observations are shown in Figures 1 and 2. Figure 1 shows the mean and standard deviation of the speeds of passenger cars and light-duty trucks for each day on which speeds were observed. The Michigan speed limit for trucks was 55 mph (88 km/h) before March 3 and thus was not affected by the new law. Observed truck speeds have a mean of 55.8 mph (89.8 km/h) with no statistically significant change over the observation period. The discussion below refers only to the speeds of light-duty vehicles.

The observed reduction in car speeds seems to have taken place in two distinct steps. The first reduction of 2.9 mph (4.7 km/h) occurred between the observations on November 8-9, 1973, just after the President's speech, and those in late November. There was no further change from late November until early March when speed reductions were still on a voluntary basis. An additional drop of 2.8 mph (4.5 km/h) occurred between March 1 and March 5, apparently as a result of the imposition of the statutory 55-mph (88-km/h) speed limit in Michigan on March 3. After police enforcement began on March 16, there was a drop in the standard deviation but no significant reduction in mean speeds. Thus the mean speed dropped by a total of 5.7 mph (9.2 km/h) between early November 1973 and early November 1974. At the same time, the standard deviation fell by 2.1 mph (3.4 km/h).

A more detailed picture of the evolution of the speed patterns over this period is shown in Figure 2, which gives the fraction of speeds less than 55, 60, 65, and 70 mph (88, 97, 105, and 113 km/h) on each day.

The effectiveness of the public appeal for voluntary speed reductions is illustrated by the reduction in mean speeds between the observations on November 8-9 and those on November 29-30, 1973. We have no comparable measurements for the period preceding the President's November 7 speech, so we cannot assess the full extent of the speed reduction on Mich-59. However, the Michigan Department of State Highways and Transportation measured an average speed of 67.9 mph (109.3 km/h) in October 1973 for typical rural freeways in Michigan. In spite of the observed reduction in mean speeds, there were very few drivers who complied fully with the suggested voluntary limit of 50 or 55 mph (80 or 88 km/h), indicating that drivers apparently responded by reducing their speeds only to the extent that they deemed appropriate, rather than by following the letter of the President's appeal.

The further reduction in speeds after the imposition of the statutory 55-mph (88-km/h) limit suggests that measures backed by law are more effective in altering driving patterns than those depending on voluntary cooperation alone. Even for the most recent observation period, only about 30 percent of the observed vehicles were below 55 mph, compared to 11 percent in early November. On the other hand, cars with speeds of more than 60 mph (97 km/h) dropped from 64 to 27 percent between the two periods.

In addition to the governmental measures for reducing highway speeds, the period from November 1973 to March 1974 witnessed a steady increase in the price of gasoline and a reduction in its availability. They may have induced drivers to conserve gasoline for reasons of economy and convenience. Conversely, the period from March 1974 through June 1974 was characterized by stabilized gasoline prices and increased availability. One might have expected that condition to lead to a trend toward increasing speeds. However, the mean speeds from March 1974 through June 1974 seem to have remained stable. The observed speed changes in the period from November 1973 to June 1974 appear to have developed in discrete steps associated with governmental actions rather than as a continuous trend either upward or downward. The observations from July 1974 through November 1974 show a small increase of 1.1 mph (1.8 km/h), as mentioned above, but this may be due to a change in the observation site.

VARIATIONAL PROPERTIES OF OBSERVED MEAN SPEEDS

In traffic engineering practice (3, 4), statistical analyses of spot speed studies have usually been based on the assumption that speeds observed under similar conditions, such as time of day, day of the week, flow, and truck volume, are random samples drawn from identical distributions. Statistically significant differences between samples are then regarded as an indication of the effect of a change in conditions.

The data obtained in this study provide a convenient opportunity to test the assumption of identically and independently distributed observed individual speeds. Under this assumption, the mean of a 15-min sample of observed speeds is expected to have a variance given by

$$\sigma_{\bar{v}}^2 = \sigma_v^2/n \qquad (1)$$

where

n = sample size,
σ_v^2 = variance of the individual observations, and
$\sigma_{\bar{v}}^2$ = variance of the sample mean $\bar{v}$.

An estimate of $\sigma_{\bar{v}}^2$ is usually provided by a sample estimate of σ_v^2 given by

Figure 1. Mean and standard deviation of passenger car speeds observed on individual days.

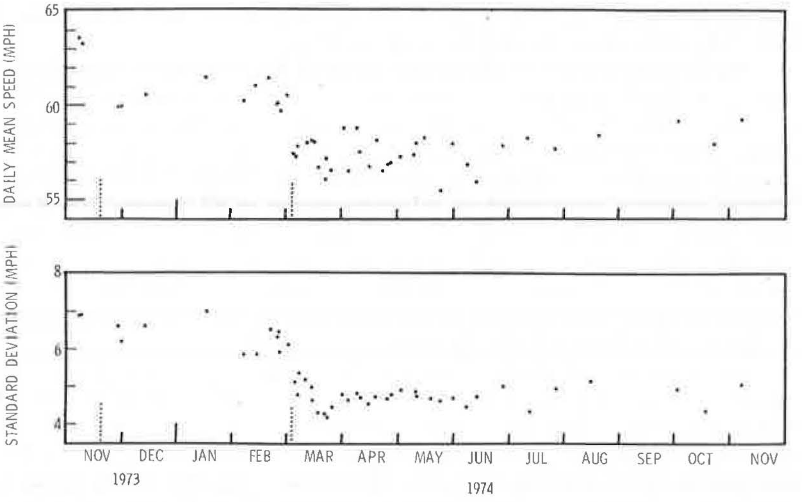

Figure 2. Fraction of car speeds less than 55, 60, 65, and 70 mph (88, 97, 105, and 113 km/h) on different days.

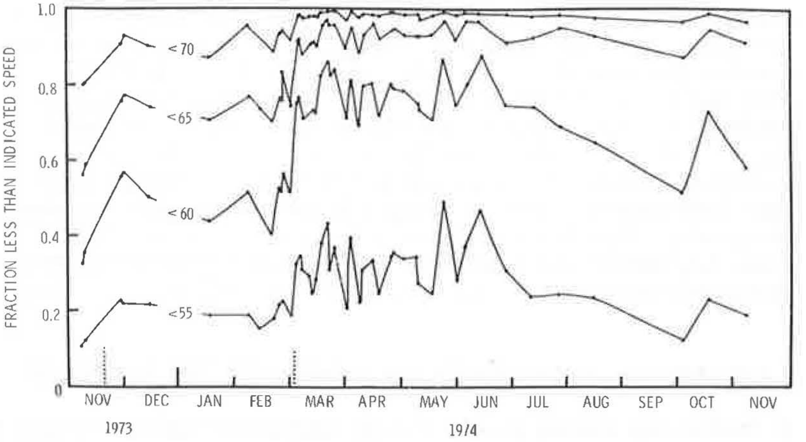

Table 1. Result of multiple classification analysis for all data.

Predictor Variable	Degrees of Freedom	Sum of Squared Deviations	F-Ratio
Period	3	666.8	204.8[a]
Day of week	4	10.3	2.4
Time of day	2	1.4	0.7
Observer	3	21.2	6.5[a]
Volume of cars	8	4.6	0.5
Volume of trucks	5	5.4	1.0
All predictors	25	696.8	24.9[a]
Residual variance	196	212.8	

[a]Significant at the 1 percent level.

Table 2. Result of multiple classification analysis for all data with date as predictor variable.

Predictor Variable	Degrees of Freedom	Sum of Squared Deviations	F-Ratio
Date	38	700.8	27.8[a]
Time of day	2	1.3	1.0
Observer	3	22.1	8.6[a]
Volume of cars	8	2.8	0.7
Volume of trucks	5	6.0	1.9
All predictors	56	802.9	22.0[a]
Residual variance	165	106.6	

[a]Significant at the 1 percent level.

$$s_{\bar{v}}^2 = \sum_{i=1}^{n} (v_i - \bar{v})^2/(n - 1) \tag{2}$$

where v_i = observed speed of an individual vehicle in the sample. The sample estimate, $s_{\bar{v}}^2$, of $\sigma_{\bar{v}}^2$ is then obtained by using equation 1. An independent estimation $S_{\bar{v}}^2$ can be obtained from repeated observations in samples of approximately n vehicles under similar conditions. The estimate of $\sigma_{\bar{v}}^2$ is then calculated from the observed mean speed $\bar{v}_j$ of each individual sample. Comparing the results from the two approaches allows a study of the stability and stationarity of the speed distributions observed under similar or different conditions.

The 222 speed samples obtained in 15-min intervals between November 8, 1973, and June 13, 1974, have been divided into four periods: November 8 to November 9, 1973; November 28, 1973, to March 1, 1974; March 5 to March 15, 1974; and March 18 to June 13, 1974. In each of these periods the daily means and standard deviations appear to be stationary.

In addition to the observed effects due to the change in conditions associated with the four time periods, each 15-min sample is also characterized by a number of other factors that may contribute systematically to the observed mean speed (5, 6). Although this study was planned so that the range of flow and time of day would be narrow, a statistical analysis was made to study possible influences from

1. Volume of cars,
2. Volume of trucks,
3. Observer,
4. Time of day, and
5. Day of week.

The variability of the 15-min samples reflects not only the inherent variability due to sampling but also possible nonstationarity in the samples and contributions from the variables mentioned above. A study of the variational properties and the contributions from the various sources of the observed 15-min mean speeds is described below.

An appropriate approach for analyzing this set of data is to adjust the observed 15-min mean speed for systematic effects due to the various variables and to compare the variance of the adjusted mean speeds with the variance expected from identical and independent observations drawn from a single speed distribution. The method used to carry out this procedure must reflect two characteristics of the data. First, some of the predictors or independent variables, such as day of the week, are nonnumerical. Second, some of the independent variables are correlated; for instance, the volume generally increased later in the day, so that volume and time of day are correlated variables. A convenient and appropriate way of dealing with data of this type is a statistical technique known as multiple classification analysis (7). In essence, this technique estimates the fraction of the variance explained by the independent variables. The significance of the explanatory power of each variable can then be tested by using the F-ratio test. Similarly, the residual or unexplained variance, with the systematic effects removed, can be compared with the variance expected under the assumption of independently and identically distributed individual speeds.

The results of the multiple classification analysis are given in Table 1. (The sum of squared deviations explained by all the predictors together is not equal to the sum of the individual contributions because of correlations among the predictor variables.) The largest fraction of the variance is predicted by the division of the data into the four apparently distinct periods. The only other predictor variable that accounts for a significant fraction of the variance is the observer recording the speed data. This effect, involving a spread of 0.7 mph (1.1 km/h) among four observers, may be due to different reaction times in reading the speed meter. It is interesting to note that there was no consistent significant effect due to varying flow rates within the range observed in the study.

The residual variance given in Table 1 is a measure of the random variability of the 15-min mean speeds after adjustment is made for systematic contributions from the six predictor variables. This quantity, which is a combination of the variations due to sampling and nonstationarity, may be compared with the variation due to sampling alone. The variability in the mean speeds due to sampling may be calculated from the observed speed distributions by using equation 1.

The individual speeds in the 15-min samples, unfortunately, also exhibit variations from sample to sample, as well as a significant difference before and after March 3, 1974. It is, therefore, not possible to make an exact comparison between the residual variance of the mean speeds estimated from the multiple classification analysis and the expected variance in the mean speeds due to sampling. The residual variance in the mean speeds has been estimated to be 1.09 $(mph)^2$ [2.8 $(km/h)^2$]. This may, however, be qualitatively compared with the range of variances due to sampling as derived from equation 1 for individual samples. The range was 0.18 to 0.83 $(mph)^2$ [0.47 to 2.2 $(km/h)^2$] during the period before March 3 and 0.07 to 0.39 $(mph)^2$ [0.18 to 1.01 $(km/h)^2$] during the period after March 3. The residual variance, which is in all cases larger than the variance attributable to sampling alone, indicates certain nonstationarity in the 15-min samples of individual speeds.

It is also of interest to determine whether the speed fluctuations among observations on the same day are as great as those among observations on different days. This question can be answered by repeating the multiple classification analysis calculation by using the observation date as a predictor variable instead of the period and the day of the week. The results are given in Table 2. The residual variance is reduced to 0.65 $(mph)^2$ [1.7 $(km/h)^2$], which is significantly less than the value of 1.09 $(mph)^2$ [2.8 $(km/h)^2$] obtained in the earlier calculation; this indicates that the variance from day to day is greater than that within a day. However, the residual variance is still larger than most of the variances due to sampling as calculated from individual 15-min speed distributions.

CONCLUSIONS AND DISCUSSION

Mean speeds of cars on the Mich-59 freeway were reduced from 63.3 to 57.6 mph (102 to 92.7 km/h) during the period of the study, and the standard deviation of the speed distribution fell from 6.9 to 5.1 mph (11.1 to 8.2 km/h).

An important aspect of freeway speeds is the connection between speed and accidents. It is well known that lower speeds lead to reduced accident severities. Traffic safety research has also shown that greater uniformity of speeds leads to reduced accident rates. The reduction in the standard deviation of speeds on Mich-59 suggests that speeds have become more uniform and hence that the freeway may have become safer.

The variational properties of observed 15-min mean speeds do not agree with the results expected if the individual speeds are identically and independently distributed, even after corrections are made for possible systematic effects. The variances in the mean speeds from day to day of 1.09 $(mph)^2$ [2.8 $(km/h)^2$] and from 15-min interval to 15-min interval of 0.65 $(mph)^2$ [1.7 $(km/h)^2$] exceeded the expected sampling variations if the speed distribution were stationary. Factors such as volume and time of day do not have strong influences on the mean speed within the range of relatively light flow under which the study was conducted.

The results indicate that, although the mean speed of 15-min observations is stochastically stationary under similar conditions, it is nonetheless a statistically distributed quantity and hence must be estimated with repeated measurements of sample means. A large sample of individual vehicle speeds on the same day, even under approximately constant conditions, is not sufficient to predict the mean speed from day to day or from one part of one day to another of similar conditions. In before and after studies, it would be more desirable to sample speeds in individual short intervals over a number of days before and after the change in conditions and then use the individual sample means as the basic data for statistical comparisons.

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