Evaluation of Techniques for Warning of Slow-Moving Vehicles Ahead

Maurice H. Lanman III*, Federal Highway Administration, Pittsfield, Maine
Harry S. Lum, Federal Highway Administration
Richard W. Lyles, Social Science Research Institute, University of Maine at Orono

This paper reports on an experiment undertaken to examine the relative effectiveness of roadside signs and vehicle markings for warning motorists about a slow-moving vehicle on the road ahead in a rural two-lane situation. In the experiment, a staged slow-moving vehicle was introduced into the traffic stream and data were taken on the reactions of motorists who overtook it. Samples of motorists were exposed to different combinations of roadside signs, vehicle markings, and types of slow-moving vehicles. The principal finding was that the use of standard four-way flashers is an effective device for reducing the hazards of the overtaking situation relative to reaction distance, speed reduction, and following characteristics. Although the effects of the roadside warning signs were positive in the vicinity of the sign placement (the slow vehicle could not be seen), there were no lasting effects relative to the actual overtaking maneuver.

In 1976, the National Safety Council (1) reported that 26 percent of all rural nonintersection accidents that involved two vehicles occurred when both vehicles were traveling in the same direction. Past research (2-4) indicates that one of the principal causes of such accidents was the differential in speed between the two vehicles involved and that the probability of a higher speed differential increased if one of the two vehicles was a truck (or other slow-moving vehicle) on a moderate or steep upgrade.

During 1977 and 1978, an experiment was undertaken at the Federal Highway Administration's (FHWA's) Maine facility in Pittsfield to evaluate several vehicle-mounted and roadside warning devices relative to their effectiveness in minimizing the accident potential when a slow-moving vehicle is overtaken by a faster one on a moderate upgrade in a rural two-lane situation.

THE EXPERIMENTAL SITUATION

The site for the experiment was a section of US-2 that was 1830 m (6000 ft) long and located between Canaan and Palmyra, Maine (Figure 1). The section includes about 1520 m (5000 ft) of grade varying between 3 and 7 percent. This section of road is part of a 24-km (15-mile) length between Canaan and Newport, Maine, which can be instrumented via use of embedded induction loops in the road at 61-m (200-ft) intervals. The loops are connected to a Raytheon 500 computer housed in the Maine facility building (5-7), which is located near the midpoint of the road test section.

The instrumentation allowed the computer to identify a subject vehicle at point B (Figure 1) and track it over this instrumented section as it overtook, and possibly passed, a slow-moving vehicle. To ensure that encounters with slow-moving vehicles were consistent with one another, a staged vehicle was inserted at point A and traveled upgrade at a fixed speed. The procedure is best illustrated by the sequence of events for a run outlined as follows:

1. The staged vehicle was at the ready on the side road at point A.
2. The computer identified the next vehicle (subject vehicle) entering the experimental section at point B and satisfying these criteria: (a) there were no other vehicles between the subject vehicle and point A and (b) the subject vehicle was moving at least 24 km/h (15 mph) faster than the staged vehicle's assigned running speed (this was to ensure that the actual overtaking occurred in zone D).
3. The computer gave the driver a go signal.
4. The driver pulled out onto the road, accelerated to the assigned running speed, and maintained that speed through the remainder of the instrumented section.
5. The computer tracked both the subject and staged vehicles relative to their positions on the grade and speeds at any point.
6. After the staged vehicle reached point E, the driver pulled off, returned to point A, and signaled the computer that he was ready to go again.

During the course of a run, the driver of the subject vehicle saw a specific sign condition at the roadside (relative to slow-moving vehicles) and then encountered a specific staged vehicle with specific markings. All data relative to the subject-vehicle driver's responses were recorded automatically on magnetic tape for later processing. Raw data were in the form of time intercepts of the embedded loops. They were later processed to reflect vehicle speeds, vehicle headways, and so forth.

INDEPENDENT AND TESTED VARIABLES

Although the principal independent variables examined in this experiment were those related to vehicle markings and roadside signs, several others were also considered and are discussed here.

Roadside Signs

One of the variables of primary interest concerned roadside signs. The basic hypothesis was that provision of a warning sign that conveyed information to the motorist about the possibility of encountering a slow-moving vehicle ahead would result in a less hazardous situation when such a slow-moving vehicle was actually sighted and overtaken.

The roadside signs that were actually deployed are illustrated in Figure 2. Briefly, the first condition was a base (i.e., no sign was deployed) that provided information regarding what motorists' reactions were when no signs were present. The second was a warning sign that read, SLOW-MOVING VEHICLES AHEAD. The message was nonstandard, straightforward, and unambiguous. The urgency of the information conveyed to motorists was typical of other warning signs.

The next sign condition had the same message but was made more emphatic by the addition of continuously flashing beacons mounted above the sign. It was hypothesized that the motorist who saw this sign received more positive (and urgent) information. The last sign condition conveyed the most positive information because the addition of the WHEN FLASHING plaque to the

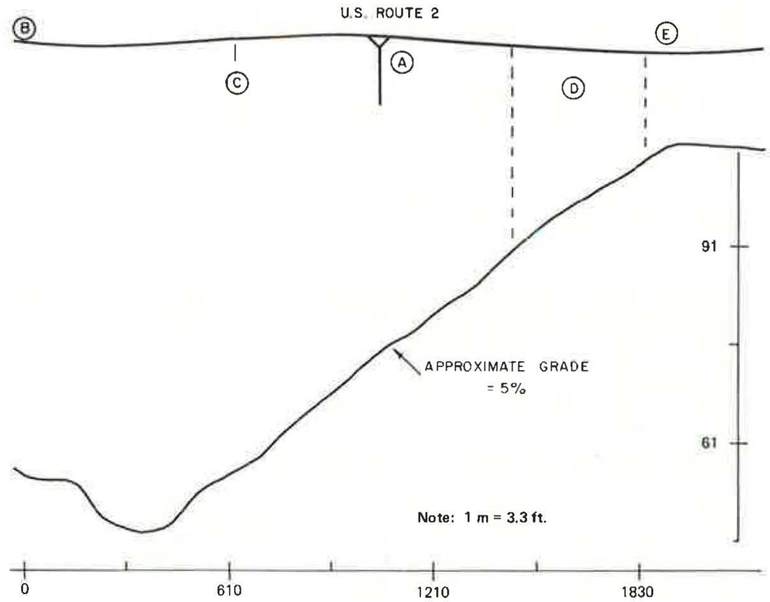
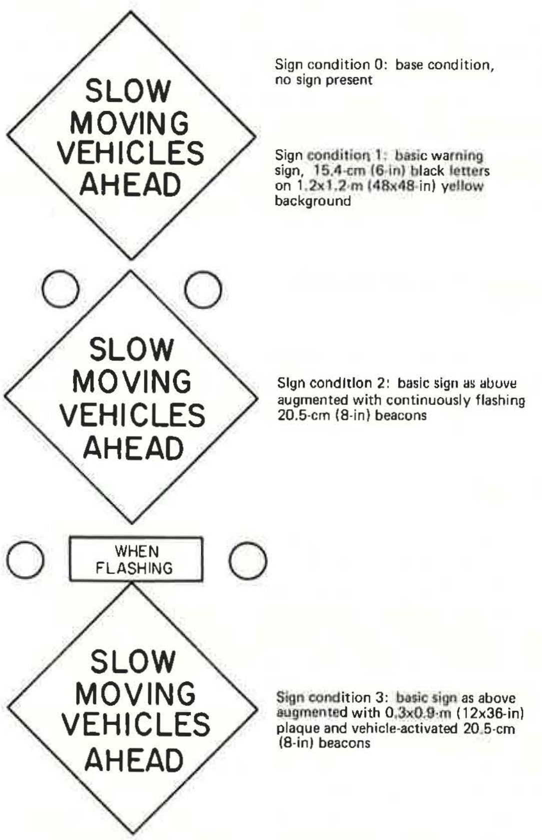


Figure 1. Plan and profile of slow-moving vehicles experiment.

Figure 2. Roadside sign conditions.



basic sign informs the motorist with virtual certainty that he or she will encounter a slow-moving vehicle. The beacons in this condition were activated by the subject vehicle's crossing of an embedded loop. Thus, the driver of the subject vehicle actually saw the beacons begin to flash.

The four sign conditions represented a base and sequentially more positive information relative to the condition to be encountered on the road ahead.

Vehicle Markings

The other key variable concerned the warning conveyed by on-board vehicle markings. The markings differed according to the type of vehicle that was used as the staged vehicle. When the single-unit truck was used, the marking conditions were simply that the truck's standard four-way flashers were or were not activated. The consideration of using standard flashers as a warning device on slow-moving trucks should help to resolve some of the disagreement among the states (and regulatory agencies) about whether such use of flashers should be recommended (8, 9).

Three conditions were defined when the tractor was the staged vehicle, including no symbol, U.S. standard, and a modified New Zealand standard (Figure 3). This was similar to the truck-marking sequence because the modified New Zealand standard differs primarily in the addition of flashers.

Slow-Moving Vehicle Type

Two types of slow-moving vehicles were used in the experiment. The first type was a truck that, when typically encountered on a road, is sometimes but not always slow moving. The second type was a farm-utility tractor, which is always slow moving. The question is, Is this differentiation apparent in motorists' reactions to the vehicles?

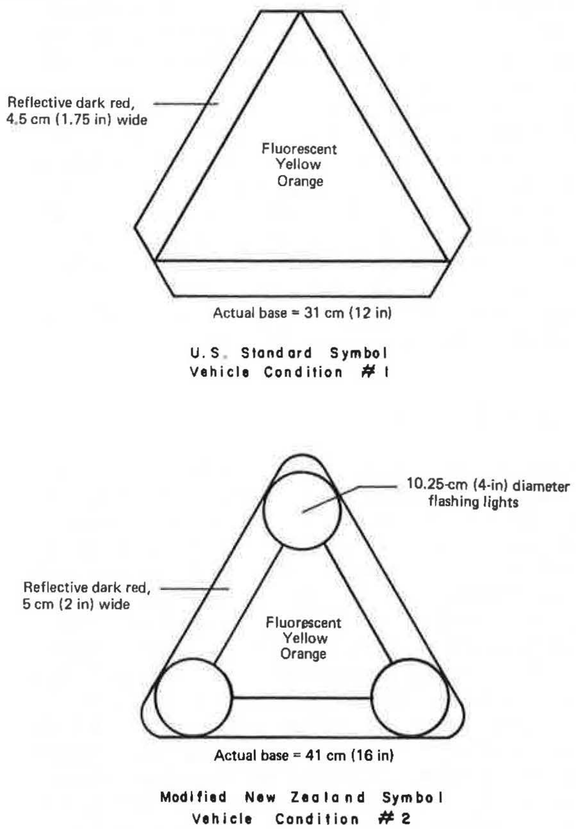
Slow-Moving Vehicle Speed

When the truck was used as the slow-moving vehicle, it was operated at two different speeds—32 and 48 km/h (20 and 30 mph). This was to determine if the effectiveness of the devices was consistent at different vehicle speeds. The tractor was operated at only 24 km/h (15 mph), a limitation imposed by the characteristics of the vehicle.

Ambient Light

The experimental situation was limited to two principal categories—day and night. In order to make this distinction as unambiguous as possible, data were not collected during dawn or dusk hours.

Figure 3. Vehicle marking conditions (tractor).



Other Variables

Several other independent variables were considered. These included the initial speed of the subject vehicle, type of subject vehicle, weather and pavement conditions, and driver familiarity with the test situation.

The speed of the subject vehicle was disregarded other than as an initial condition of acceptance, that is, a subject vehicle had to be moving at least 24 km/h (15 mph) faster than the staged vehicle, under the assumption that all combinations of test conditions would have similar distributions of fast and slow drivers.

Weather was a controlled variable to the extent that only data collected under dry road conditions and good visibility were used. The night phase of the experiment gave a reasonable approximation of driver reaction under less-than-optimal visibility.

A stratification had been intended for those subject vehicles that passed the staged vehicle and those that did not. After data collection began, it was found that this stratification was meaningful only when the tractor was the slow-moving vehicle (not enough vehicles passed the truck). Therefore, most of the results are based on vehicles that did not pass.

Because of the difficulty of obtaining adequate numbers of nonpassenger vehicles in the samples, only passenger cars (and pickup trucks) were considered as subject vehicles (e.g., heavier trucks and recreational vehicles were excluded). The issue of driver familiarity with the site is discussed later in this paper. However, no distinction was made between familiar and unfamiliar drivers in the data-collection process.

DEPENDENT (RESPONSE) VARIABLES

Data were collected under the various combinations of independent variables—for example, roadside sign condition 1; vehicle marking 2; truck, 32 km/h (20 mph); and day—until the appropriate cells (variable combinations) were filled in order to undertake statistical testing.

As described, each subject vehicle was tracked from the time it entered the instrumented section to the time it left. During this period, the time interceptions of the sensing devices were recorded for the subject vehicle. This information was then processed on site to produce values for a variety of dependent, or driver response, variables.

Originally, data on 16 variables were produced. These included subject vehicle speed as it entered the system, speed reductions at various points, distance (headway) between the staged and subject vehicles, and passing characteristics. In addition, an attempt was made to directly consider the effects of a vehicle's entry speed by normalizing the basic variables by the entry speed.

The set of variables is divided into two groups—early grade and overtaking. Early grade variables are those that relate to a subject vehicle's behavior before the slow-moving vehicle was sighted. Overtaking variables are those that are relevant after the slow vehicle could be seen by the driver of the subject vehicle.

ANALYSIS AND RESULTS

The experiment design that has been described to this point is a multifactor design that theoretically results in 4(roadside sign conditions) × 2(vehicle markings) × 2(slow-moving vehicle speed) × 2(ambient light), or 32 cells with the truck as slow-moving vehicle. Similarly, considering the tractor, the analogous design consists of 48 cells (4 roadside sign conditions × 3 vehicle-marking conditions × 2 light conditions × 2 passing conditions). As will be noted, several cells were eliminated from the tractor design due to lack of data.

The analysis that took place had three levels: (a) consideration of basic descriptive statistics (for all variables on all cells), (b) one-way analyses of variances (ANOVAs) with several independent variables held constant and a series of multiple comparisons (contrasts), and (c) higher-order ANOVAs.

Overall Results

The general results are summarized in Tables 1 and 2. The major finding of the research was that the use of four-way flashers on a slow-moving vehicle has a significant positive effect on overtaking vehicles in terms of initial reaction distance, closing rate, and minimum following headway. The effect of the roadside signs was limited to an initial effect in the vicinity of the sign placement. After visual contact was made with the slow-moving vehicle and the actual overtaking maneuver was commenced, there appeared to be little, if any, carryover effect due to the signs.

Note that no results are shown for the "truck, 48 km/h (30 mph), night" or "tractor, night" categories in Tables 1 and 2. This is due to the fact that the night phase had to be curtailed because of a time restraint.

The following discussion is based on the first two levels of analysis: consideration of the descriptive statistics and one-way ANOVAs with appropriate multiple comparisons. The results stated were consistent for these two levels. The results of the third level of analysis (higher-order ANOVAs) were inconsequential. Several of the key two-way ANOVAs were

Table 1. Summary of four-way flasher effects.

Variable	Day			Night
	Truck (32 km/h)	Truck (48 km/h)	Tractor	Truck (32 km/h)
Early grade				
Entry speed	No	No	No	No
Early grade speed	No	No	No	No
Initial speed reduction	No	No	No	No
Overtaking				
Reaction distance	Yes	M	No	Yes
Maximum speed reduction	Yes	No	No	Yes
Minimum headway	Yes	Yes	M	M
Time to collision	Yes	Yes	M	M

Notes: 1 km = 0.6 mile.
Comparisons were made (for all four sign conditions) between flasher and nonflasher effects.
Yes = Flashers generally had a significant positive effect.
M = Flashers generally had a marginally significant positive effect.
No = Flashers generally had no effect.

Table 2. Summary of roadside sign effects.

Variable	Day			Night
	Truck (32 km/h)	Truck (48 km/h)	Tractor	Truck (32 km/h)
Early grade				
Entry speed	No	No	No	No
Early grade speed	Yes	Yes	Yes	Yes
Initial speed reduction	Yes	Yes	Yes	Yes
Overtaking				
Reaction distance	M	No	No	M
Maximum speed reduction	No	No	M	No
Minimum headway	No	M	No	No
Time to collision	No	No	M	No

Notes: 1 km = 0.6 mile.
Each variable was reviewed for the range of signs, and general trends were noted.
Yes = Signs generally had a positive effect on driver behavior.
M = Sign effect was mixed—no effect in some instances and a positive effect in others.
No = Sign effects appear to be negligible.

undertaken to examine the interaction between vehicle markings and roadside signs. However, the latter analysis showed no definable trend. When actual values are given in the following report of results on a variable-by-variable basis, it should be noted that the differences are statistically valid at the 0.05 level.

Early Grade Variables

Entry Speed

The average entry speeds of the subject vehicles in the cells provide the basis for a test to determine if each sample of vehicles was similar (i.e., same entry speed for all cells). Examination of the values obtained indicated that there were no significant differences among the samples other than the somewhat lower speeds in evidence at night—about 3 km/h (2 mph)—relative to those during the day and the difference between the samples obtained for the two truck speeds. The first result is typical of the difference between day and night average speeds in general. The latter result is explained by the selection rule for subject vehicles—that is, the initial speed must be equal to or greater than the slow vehicle's speed plus 24 km/h (15 mph)—which tends to eliminate some slower vehicles from the sample selected when the slow-vehicle speed was 48 km/h (30 mph). Typical entry speeds were somewhat in excess of 80 km/h (50 mph). These differences notwithstanding, the comparison of entry speeds showed that the samples were similar.

Early Grade Speed

If a slow-moving vehicle used four-way flashers is not relevant in this instance because the vehicle was not in sight when this variable was measured. Any differences among the samples due to the use of four-way flashers would have been cause for concern. However, no differences were noted.

Although the slow vehicle was not in sight when this variable was calculated, the signs were. The effect of increasing the amount of positive information conveyed by a sign was detectable and the lighted signs had the most effect. For example, when truck speed was 32 km/h (20 mph) during the day, the vehicle-activated sign resulted in early grade speeds of about 77 km/h (48 mph) or roughly 5 km/h (3 mph) less than the base condition. These results were typical of both the day and night phases, regardless of the type of slow-moving vehicle.

Initial Speed Reduction

The results from the consideration of the initial speed reductions are consistent with those for the early grade speeds. That is, the lighted signs resulted in a significant speed reduction relative to the base roadside sign condition. The unlighted sign did not prove to be any more effective than no sign. In fact, the motorists who saw no roadside sign (the base condition) or the basic warning sign tended to show a slight increase in speed. The increase may be due to the attempt to gain speed for the grade ahead, which indicates that the basic message had no immediate effect. These results are consistent for both ambient light conditions and vehicle types. Typical values for the initial speed reductions [truck speed = 32 km/h (20 mph), day] are a decrease of 1-2 km/h ($^2/_3$-$1^1/_4$ mph) for the vehicle-activated sign versus an increase of about 1.6 km/h (1 mph) for the base condition or the basic warning sign.

Overtaking Variables

Tractor Versus Truck as Slow-Moving Vehicle

The aforementioned results for the early grade variables were basically consistent regardless of slow-moving vehicle type. Reiterating an earlier statement, the slow-moving vehicle type should make no difference because it was not in sight when the early grade variables were calculated. The remaining variables to be discussed are concerned with the actual overtaking maneuver. The discussion is based primarily on data when the truck was the slow-moving vehicle. When the tractor was used, there were no readily discernible trends in the results. Although the slow-moving vehicle symbol that was augmented with flashers (modified New Zealand) was marginally more effective than the U.S. standard symbol, the differences were not statistically significant. Thus, the following is based on truck data. For all truck data, no passing vehicles were included in the samples.

Reaction Distance

Reaction distance is a measure of how far back (from the slow-moving vehicle) a 10 percent reduction from early grade speed actually occurred. Subject vehicles that overtook slow vehicles—trucks traveling at 32 km/h (20 mph) during the day—without four-way flashers had typical values for a reaction distance of 122-152 m (400-500 ft). When the slow vehicle was displaying four-way flashers, the reaction distance generally increased between 46 and 61 m (150 and 200 ft). Values at night ranged somewhat higher; the use of flashers increased the reaction distance to 198-229 m (650-750 ft).

Maximum Speed Reduction

In general, a lower maximum speed reduction is a positive effect; this indicates that the velocity profile of the overtaking (subject) vehicle is less abrupt (i.e., potential for panic braking decreases). Considering the sign effects, there was no recognizable trend of increasing or decreasing values. Thus, the sign effects appear negligible. However, when the subject vehicles were overtaking slow vehicles displaying four-way flashers, the maximum speed reductions were typically 15-20 percent lower than when they were overtaking slow vehicles with no display—for example, there was a reduction of 8.3 km/h (5.2 mph) versus 10.1 km/h (6.3 mph). These results were fairly consistent for different slow-moving vehicle speeds and for both day and night.

Minimum Headway

The minimum headway (between the subject vehicle and the slow vehicle) attained can be compared directly to such rules of thumb as one car length per 16 km/h (10 mph), the safe following headway, or the 2-s rule. In this experiment, headways of less-than-safe following distance were generally observed. However, in several instances, when the slow-moving vehicle was displaying four-way flashers, the rule was satisfied. When the truck was moving at 32 km/h (20 mph), the activated four-way flashers resulted in headways that were typically more than 4.6 m (15 ft). When the four-way flashers were not in use, values were about 6.7-8.2 m (22-27 ft). When they were in use, values ranged from 9.8 to 12.2 m (32 to 40 ft). For a truck speed of 48 km/h (30 mph), the results were similar. It should also be noted that there appeared to be a possible residual effect due to the roadside sign in the 48-km/h truck speed category. This effect could not be verified with additional analysis.

Minimum Time to Collision

Typical results showed that times to collision averaged 6.8 s when four-way flashers were not in use. Use of the flashers resulted in an average increase of about 35 percent to approximately 9.2 s. These results were similar for both truck speeds and at night.

Comparison of Passing and Nonpassing Vehicles

When the slow-moving vehicle was the truck, insufficient data were collected for any comparison at all. However, when the tractor was the slow-moving vehicle, there were a fair number of passing vehicles. Although there were not enough passing vehicles for significant testing, several trends did emerge. Subject vehicles that eventually passed the tractor generally entered the test zone at a higher speed, slowed less in the vicinity of the signs, and generally traveled through the zone more rapidly than their nonpassing counterparts.

CONCLUSION

One assumption in the experiment that deserves further comment concerns familiar (i.e., repeat) and unfamiliar drivers. It would seem reasonable to expect drivers who went through the test area several times to react to the test situation differently from those who encountered it only once. Most daytime data were collected during periods (summer) when the traffic mix on US-2 included out-of-state travelers (up to 50 percent) who could be considered unfamiliar with the area and who would have unbiased reactions. Likewise, many of the in-state drivers during this same period were probably only occasional users of the road. Thus, it is argued that the effects of familiar drivers were minimal for the daytime data. Furthermore, because the results of the night phase were quite similar to those of the day phase, it can be concluded that the effects of familiar drivers were minimal. The effects of familiar drivers notwithstanding, the results of the experiment may be summarized as follows:

1. Activation of four-way flashers on slow-moving trucks is an effective device for reducing the accident potential when such vehicles are overtaken by faster-moving vehicles. Measures of effectiveness included variables that describe the overtaking maneuver (e.g., minimum headway).
2. The four-way flashers are as effective during the day as they are at night.
3. In terms of the variables measured in this experiment, the roadside signs are relatively ineffective as warning devices for the overtaking situation. That is, motorists who saw the signs that caused immediate reaction did not generally behave any differently at the point of overtaking from those who saw no sign.
4. Roadside signs may serve to alert the driver of a potential situation (e.g., there is a difference in early grade speeds); however, no consistently positive effects were noted at the point of overtaking.
5. When the roadside signs are effective, those that are more emphatic (i.e., the lighted ones) are generally more effective.
6. There is some evidence of an interactive effect between the more effective roadside signs and the use of four-way flashers, but it is not statistically significant.
7. Reactions to the different warning devices on the tractor are inconclusive. The modified New Zealand symbol was often slightly more effective than the standard U.S. symbol, although the differences were not statistically significant. It may be that the impact of the odd vehicle on the road masks any difference in effect between vehicle markings.
8. Drivers who tended to enter the instrumented section at higher speeds also tended to respond less to the roadside signs, maintain a higher rate of speed through the section, and pass the slow-moving vehicle.

These results demonstrate the need for reconsidering state and federal standards that preclude the use of four-way flashers on slow-moving vehicles. Such use has been shown to be effective relative to reducing the accident potential of overtaking maneuvers. Roadside warning signs, on the other hand, were shown to be ineffective in the situation examined in this experiment.

The use of four-way flashers for slow-moving vehicles constitutes a cost-effective and easily implementable safety device because they are already standard equipment on recent-model vehicles.

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**M. H. Lanman III is now with Gould and Company, Houston, Texas.*