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16. Abstract

This report describes a series of experiments that were conducted to examine the effectiveness of four-way flashers. Both the disabled vehicle situation and the slow-moving vehicle situation were examined at two- and four-lane locations under both daylight and nighttime conditions. The disabled vehicle tests involved parking a test vehicle (either a car or a tractor-trailer) at the side of the road and monitoring the behavior of drivers. The slow-moving vehicle tests involved introducing a staged slow-moving vehicle (either a car or a tractor-trailer) into the traffic stream and observing the overtaking vehicles. At the disabled vehicle, red and amber four-way flashers as well as flares, reflectorized triangles, headlights, and other situational factors were evaluated. For the slow-moving vehicle tests, the effects of red and amber flashers as well as a 30 and 40 mph (48.3 and 64.4 kph) slow-moving vehicle were examined.

For both the disabled and the slow-moving vehicle situations, it was found that four-way flashers are effective at reducing the inherent danger. In the disabled situation, it was found that approaching motorists slow down sooner and slow down more when flashers are displayed. In the slow-moving situation, it was found that drivers of overtaking vehicles approach more cautiously and pass more carefully. In both situations flashers increase the awareness of the drivers of overtaking vehicles.

Other volumes in this series include:
Volume 2. - Einal Report Volume 3. - Appendixes

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Introduction

For more than ten years, hazard warning lights, or four-way flashers, have been required motor vehicle safety equipment. Unfortunately, authorities are not in agreement regarding the most safety-promoting use of flashers. Some states require four-way flashers for vehicles traveling slower than 40 mph (64.4 kph) on interstates and turnpikes. Certain states prohibit their use on any moving vehicle, mandating that they be limited to vehicles disabled on the roadway or on the shoulder. Other regulations state that flashers should only be displayed on disabled trucks until the driver can deploy other emergency warning equipment.

The variance in these regulations results from different subjective opinions of how drivers actually interpret and respond to flashers. The purpose of this study was to obtain sound, objective data on the nature of drivers' responses to flashers. The basic problem was to determine what effect flashers have on the traffic stream approaching a slow-moving or a disabled vehicle.

The study was performed in five tasks, as shown in Figure 1. Task A involved determining the legal and operational practices associated with using four-way flashers. Task B defined the scope and characteristics of the hazards involved in situations where flashers might be effective. Using inputs from Tasks A and B, an experimental plan was developed (Task C) to evaluate the effectiveness of four-way flashers. In Task D two major field studies were conducted to determine the effectiveness of flashers. The effects of staged disabled vehicles parked on the shoulder of the roadway were assessed in the first field

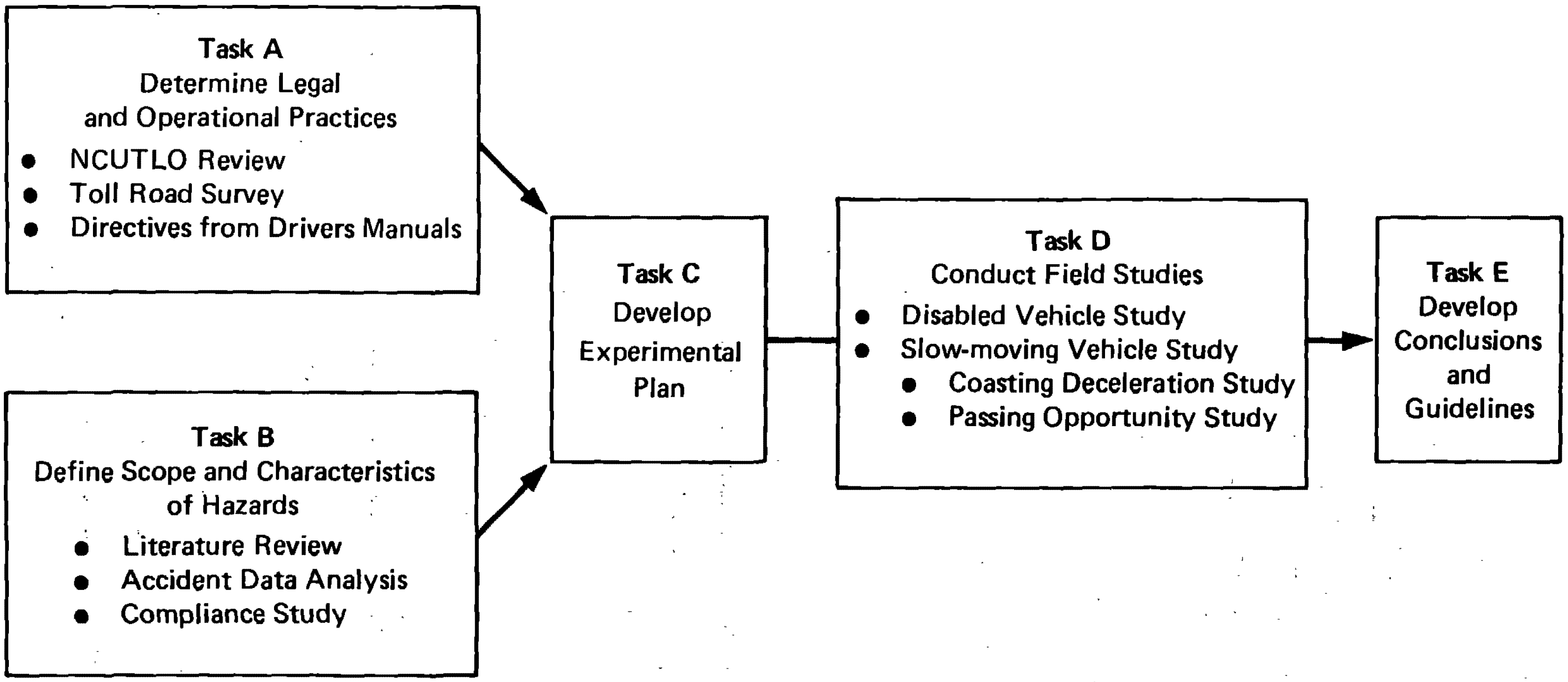


Figure 1. Project Tasks

study. In the second study a slow-moving vehicle was introduced into the traffic stream. Both studies were conducted on four sections of instrumented roadway using both a car and a tractor-trailer as test vehicles. The instrumentation permitted the reconstruction and evaluation of the behavior of approaching traffic. The final activity, Task E, involved developing conclusions and guidelines relative to flasher usage for both the disabled and slow-moving vehicle situations.

This Executive Summary follows the basic organization of the project tasks. Five major areas are addressed:

- Background
- Research Methodology
- Results of Disabled Vehicle Study
- Results of Slow-Moving Vehicle Study
- Conclusions and Guidelines

The Background section covers several areas that were addressed in order to determine the legal and operational practices and to define the scope and characteristics of hazards associated with flasher usage. In all, the Background section contains six parts:

- Literature review
- Traffic regulations and legal issues
- Use of flashers on tollroads
- Directives from drivers manuals
- Analysis of accident reports
- Compliance study.

Research Methodology describes the techniques and procedures that were used in the disabled vehicle study and the slow-moving vehicle study. Three topics are included:

- Independent variables
- Dependent variables
- Methodology.

The third area includes the results and conclusions of the study on the effects of four-way flashers in the disabled vehicle condition. Both a disabled car and a disabled truck were used. Although the major comparisons made were between the flashers-on and the flashers-off conditions, a number of other conditions were evaluated. These included flares, warning triangles, headlights, and the presence of a "bystander" near the vehicle.

The fourth section presents the results and conclusions of the study on the effects of flashers on traffic overtaking a slow-moving vehicle. As in the disabled vehicle test, both a car and a truck were used as the slow-moving test vehicles. Effects of slow-moving vehicles were tested at 30 mph (48.3 kph) and 40 mph (64.4 kph).

The final section is a brief statement of the conclusions of the research and a listing of suggested guidelines for the use of four-way flashers.

Background

The literature review revealed that there is an accident problem involving rear-end collisions that is related to speed differentials between two vehicles in the traffic stream. Drivers seem to have difficulty perceiving the speed differentials between their own vehicle and the vehicles they are approaching. Although some work has addressed the visibility or conspicuity of various warning devices, including flashers, there has been very little investigation of the behavioral effect of flashers on approaching traffic. Recent work done at the Federal Highway Administration (FHWA) Maine Facility has suggested that flashers do have a positive safety benefit in both the slow-moving and disabled vehicle conditions.

The National Committee on Uniform Traffic Laws and Ordinances (NCUTLO) prepared a review of the current status of state laws and federal regulations concerning flasher usage. Substantial differences were found among the various state laws. There is also considerable disagreement between some state and local regulations and the Federal Motor Carrier Safety regulations. The NCUTLO concluded that there is a need for a broad-based policy decision regarding the use of flashers.

A survey of the instructions given to drivers on tollroads revealed that most of the authorities do not provide special instructions regarding flasher usage in either the slow-moving or disabled vehicle situations. Only three states use signs to indicate that slow-moving vehicles should display flashers.

A review of information from current drivers manuals from the 50 states and the District of Columbia indicated that 26 states do not mention the use of flashers. Fifteen states recommend <u>or</u> suggest using flashers when disabled; 11 recommend using flashers in emergencies. Although two states recommend that drivers of slow-moving vehicles activate their flashers, two other states specifically prohibit using flashers on moving vehicles.

An analysis of accident reports from North Carolina and Virginia showed that between 5 and 10% of the accidents occurring on hilly roadway sections may involve a misreading of relative vehicle speeds. These accidents do not appear to be appreciably different from other accidents occurring on the same roadways. They tend to occur during the same time of day, under the same weather conditions and be equally severe.

A small-scale field effort was conducted to determine the level of compliance to directives that vehicles moving less than 40 mph (64.4 kph) should display flashers. Using a radar gun to measure vehicle speed, it was determined that 61.5% of the vehicles traveling less than 40 mph (64.4 kph) were in compliance. Although compliance was slightly higher at night (65.3%) than during the day (58.5%), the presence of a sign repeating the direction made less than half a percent difference.

Research Design and Methodology

A research methodology was developed to evaluate the effects of flashers on the behavior of traffic approaching either a disabled vehicle or a slow-moving vehicle. Developing the experimental plan involved determining the independent variables, the dependent variables, and the methodology.

The independent variables of interest were those involving the experimental sites, the test vehicles, and the various test conditions. There were four experimental sites, two with four-lane and two with two-lane roadways. One of the four-lane sites and one of the two-lane sites had a steep (5-6%) upgrade. The other sites had slight (2%) upgrades. All of the experimental sites were in Maryland. Since data were collected under daylight and nighttime conditions, there were a total of eight experimental test situations.

A car and a truck (tractor-trailer) were used as test vehicles. Both test vehicles were evaluated with the flashers off and with the flashers on. The flashers-on condition for the test car was designed to evaluate both red and amber flashers.

The final set of independent variables involves the various test conditions. Two basic conditions, the disabled vehicle and the slow-moving vehicle, were considered. The disabled vehicle condition, in turn, involved a total of ten test conditions including headlights, flares, reflectorized triangles, and the presence of situational cues such as a bystander or a raised hood or trunk. The slow-moving vehicle condition involved the test vehicles moving at either 30 mph (48.3 kph) or 40 mph (64.4 kph).

Sets of dependent measures, or measures of effectiveness (MOEs), were developed for the disabled vehicle tests and for the slow-moving vehicle tests. The disabled vehicle MOEs included vehicle speed, lateral placement, acceleration, and headway. A number of other dependent measures, including erratic maneuvers and lane changing behavior, were also examined. Of the 14 dependent measures that were developed, vehicle speed (at various points relative to the disabled vehicle), mean speed (in the general vicinity of the disabled vehicle), and lateral placement (at various points relative to the disabled vehicle) were the most sensitive.

Eight dependent measures were developed to evaluate flasher effectiveness in the moving vehicle condition. Four of these were found to be the most sensitive:

- Distance at Initial Reaction Point: The distance the overtaking vehicle was behind the test vehicle when a speed reduction of 1 mph (1.6 kph) was first observed.

- Time to Collision: The time to the theoretical collision of the test vehicle and the overtaking vehicle if both drivers maintained their respective speeds. The time is computed from the point where the 1 mph (1.6 kph) speed reduction was observed.

- Distance at Maximum Deceleration: The distance that the overtaking vehicle was behind the test vehicle when the maximum deceleration occurred.

- Passer Distance at Lane Change: The distance that the overtaking vehicle was behind the test vehicle when the overtaking vehicle changed lanes to pass.

The basic research methodology involved staging the disabled vehicle condition and the slow-moving vehicle condition. The Traffic Evaluator System (TES) was deployed at each of the four test sites. The TES permits the reconstruction of vehicle trajectories and interactions as the subject and test vehicles pass through an instrumented section of highway. The instrumentation consisted of an array of nine pairs of tapeswitches located 300 feet (9.15 m) apart.

The disabled vehicle condition was staged by parking the disabled vehicle (either the car or the tractor-trailer) on the shoulder of the roadway two-thirds of the way through the array. The vehicle was placed 1.5 to 2 feet (0.45 to 0.6 m) from the outside pavement edge marking. The various disabled vehicle conditions were tested by making changes to the basic disabled vehicle condition, i.e., turning the flashers on, turning the headlights on, deploying flares or emergency triangles, etc.

The moving vehicle condition was staged by introducing the test vehicle into the traffic stream so that the interaction between the slow-moving test vehicle and the overtaking subject vehicle would occur in the instrumented roadway section. All four experimental sites had some type of visual obstruction that prevented approaching drivers from seeing either the disabled vehicle or the slow-moving vehicle until they were in the instrumented array and their behavior could be monitored.

Results of the Disabled Vehicle Study

A variety of techniques for warning approaching motorists of a disabled vehicle were evaluated. The following summarizes the results of the evaluation of each of the techniques:

Red and Amber Flashers. No differential effectiveness was found between red and amber flashers. This was true for both day and night conditions.

Parking lights Displayed. There is strong evidence that displaying parking lights increased the safety potential. The effect was further enhanced when parking lights were combined with four-way flashers.

Flares and Warning Triangles. The use of flares was found to be the single most effective way to reduce the accident potential in the vicinity of the disabled vehicle. The flares were more effective when displayed at the disabled car than at the disabled truck. The reflectorized warning triangles produced a similar, but smaller, effect. The warning triangles were relatively ineffective during the day, but at night showed an effect comparable to that produced by the parking lights. Two warning device placements were tested. The standard procedure (one device directly behind the vehicle with additional devices at 100 and 200 feet [30 and 60 m]) was found more effective than the tapered placement. (One device in front of the vehicle, one directly behind and the third 100 feet [30 m] behind). When flares were deployed there were no consistent effects produced by the addition of four-way flashers. The addition of flashers to the situations where triangles were displayed resulted in a small increase in effectiveness.

Bystanders. Approaching traffic responded to the presence of a bystander near the disabled car. The nature and extent of the change in approach behavior was not affected by the presence or absence of four-way flashers. The presence of the bystander produced a reduction in accident potential. The response of the approaching traffic was to slow down. Surprisingly, there was no evidence of a tendency to drive more to the left.

Raised Hood and Trunk. The effect produced by having either the hood or the trunk raised on the disabled car was similar to that produced by the presence of a bystander. The magnitude of the changes was generally not as great. Unlike the bystander condition, there was an increase in accident reduction potential produced by the addition of four-way flashers to the raised hood and trunk condition.

Four-Way Flasher Effects. The experimental results provide a positive indication that four-way flashers are an effective means of improving safety in the vicinity of a disabled vehicle. Consistent, significant effects were found in two measures of effectiveness (MOEs): the speed of vehicles at the disabled vehicle and the average speed of approaching vehicles in the vicinity (between 1,200 feet [360 m] before and 900 feet [270 m] after) of the disabled vehicle. Although the absolute amount of the speed reduction was small, the effect was very consistent across most of the test conditions. The speed reductions measured at the disabled vehicle varied from 0.1 mph to 4.5 mph (0.2 to 7.2 kph). The reduction in mean speed before and after the disabled vehicle varied from 0.1 to 3.2 mph (0.2 to 5.2 kph).

Table 1 illustrates the consistency of the effects of four-way flashers across the eight experimental conditions. That table shows the safety improvement (+) or decrease (-) found for

Table 1.

Safety Implications of Four-Way Flashers

SAFETY IMPLICATIONS
REDUCTION IN SPEED, AT THE DISABLED VEHICLE

TEST CONDITION \ EXPERIMENTAL SITUATION	DAY				NIGHT			
	TWO-LANE		FOUR-LANE		TWO-LANE		FOUR-LANE	
	STEEP	SLIGHT	STEEP	SLIGHT	STEEP	SLIGHT	STEEP	SLIGHT
DISABLED CAR	+	+	+	+	+	—	+	—
DISABLED TRUCK	+	+	—	+	+	+	●	+

SAFETY IMPLICATIONS
REDUCTION IN SPEED, IN THE VICINITY OF THE DISABLED VEHICLE

TEST CONDITION \ EXPERIMENTAL SITUATION	DAY				NIGHT			
	TWO-LANE		FOUR-LANE		TWO-LANE		FOUR-LANE	
	STEEP	SLIGHT	STEEP	SLIGHT	STEEP	SLIGHT	STEEP	SLIGHT
DISABLED CAR	+	+	+	+	+	—	+	O
DISABLED TRUCK	+	+	+	O	+	+	●	+

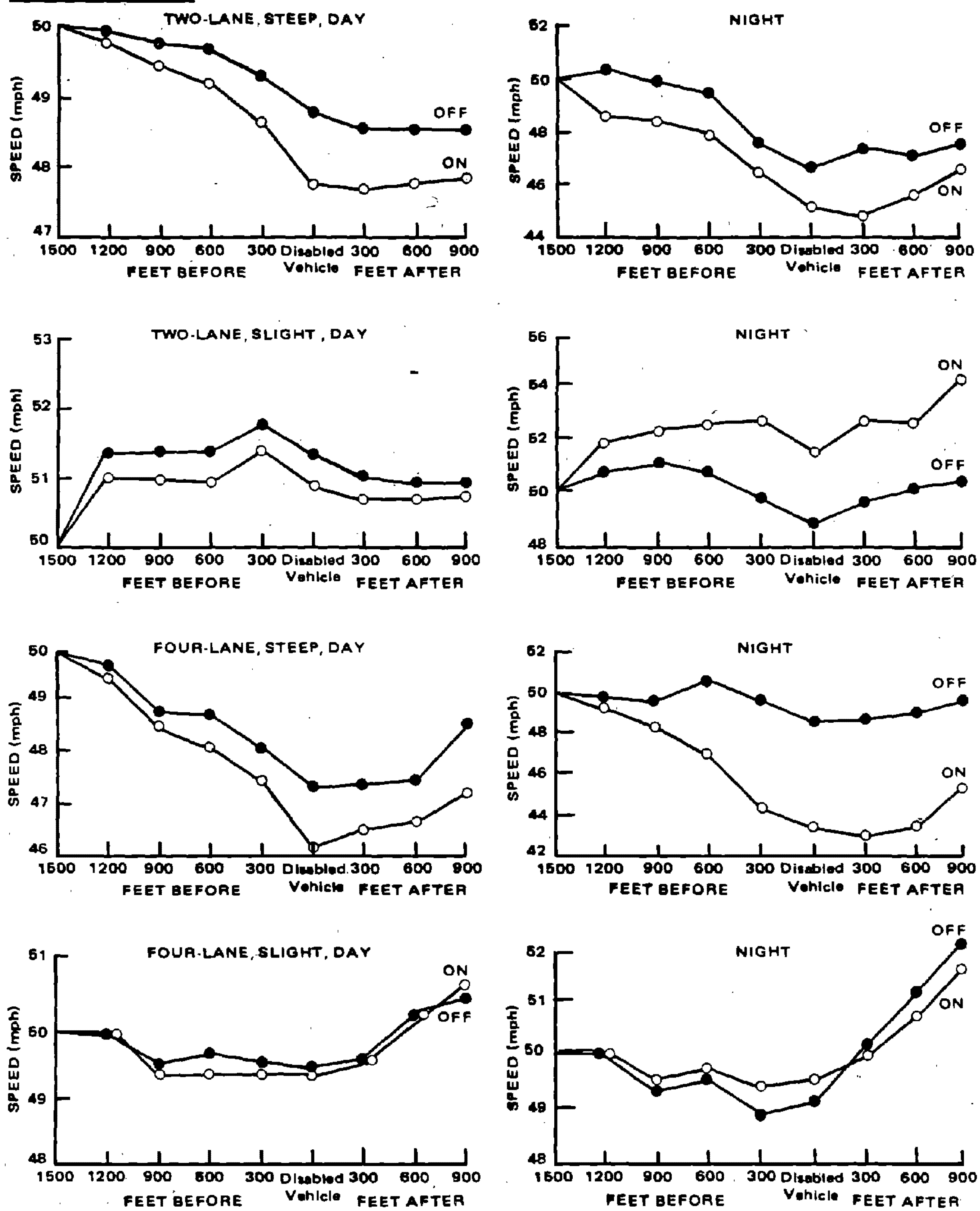
Legend:
+ = Positive effect on safety
— = Negative effect on safety
O = No effect
● = No data

each of the eight experimental situations. The top half of the table shows the safety implications of the speed reductions found at the disabled vehicle. The bottom half of the table shows the safety implications of the mean speed reductions in the vicinity of the disabled vehicle, 1500 feet (450 m) before to 900 feet (270 m) after. For the disabled car test, six of the eight situations show improvement for both of the MOEs. For the disabled truck test, no data were available from the four-lane steep grade site under night conditions. Six of the seven remaining experimental situations show an improvement for both MOEs.

Further confirmation of the benefit in safety attributable to the use of four-way flashers is seen in the speed profiles of the observed traffic stream as it approached and passed the disabled test experimental situations. Only at the two-lane, slight upgrade site at night, did approaching vehicles slow down more and slow down sooner for the flasher-off test vehicle. We suspect that this effect is due to a large-scale radar speed enforcement campaign that was conducted near the test site. For the other 7 test conditions, approaching traffic slowed more for the flashers-on conditions. In some of the graphs, the differences between the flashers-on and flashers-off conditions are apparent as much as 1,200 feet (360 m) from the disabled vehicle. In the remainder of the graphs, the difference is apparent at 600 feet (180 m) before the disabled vehicle. These profiles suggest that the four-way flashers increase the awareness of approaching drivers.

In order to enhance safety, it is not essential that drivers of approaching vehicles slow down significantly. What is essential is that they be aware of a potential hazard and be ready to react to it. The differences between the speed profiles for the steep upgrades and the slight upgrades suggest that a driver's overt response, a slight decrease in accelerator pedal pressure, might be similar across conditions and that the resulting speed reduction is a function of the degree of upgrade.

Disabled Car



1 mph = 1.6 kph

1 foot = .3 m

Figure 2. Speed Profiles: All Situations Flashers On vs. Off, Car

Results of the Slow-Moving Vehicle Study

The use of four-way flashers has a persistent, systematic effect on each of the dependent measures considered. Changes in the dependent measure values have direct implications on the effectiveness of the flashers in reducing the potential for rear-end collisions.

Four of the dependent measures have clear implications relative to the effectiveness of four-way flashers:

- Initial Reaction Distance (IRD): An increase in initial reaction distance indicates that drivers of overtaking vehicles responded to the slow-moving vehicle with flashers at a greater distance than they did to a slow-moving vehicle without flashers.

- Time to Collision (TTC): An increase in the time to collision measure indicates that drivers of the approaching vehicles slowed down earlier, so that the theoretical rear-end collision was less likely.

- Distance at Maximum Deceleration (DMD): An increase in DMD indicates that the point of greatest deceleration occurs farther from the slow-moving vehicle, and that vehicles with activated flashers caused drivers of approaching vehicles to slow down farther from the slow-moving vehicle.

- Passer Distance at Lane Change (PDLC): The drivers of passing vehicles changed lanes farther from the slow-moving vehicle. It is apparent that drivers were aware of the speed differential sooner and responded appropriately.

The persistence of the effects of flashers was evident. The results were not consistently significant in a statistical sense, but the changes in each measure were remarkably consistent across a variety of test conditions. Table 2 summarizes the safety implications of the measures of effectiveness for each of the eight test situations. The data shown are for the car and truck test vehicles combined over both day and night conditions. A plus sign (+) indicates an improvement in safety. The changes in the four MOEs indicate that flashers improved safety for all eight test situations.

The magnitude of the changes observed in each MOE is shown in Figure 3. The data are presented for the slow-moving car and the slow-moving truck under day and night conditions. Also shown is the car and truck combined for day, car and truck combined for night, and the car and truck combined for both day and night.

The values indicated are the average increases across the eight test situations. Flashers increased the intial reaction distance from 49.3 to 113.9 feet (14.8 to 34.2 m) with an average increase of 67.7 feet (20.3 m). Flashers increased the time to collision from 3.0 to 7.5 seconds with an average of 4.3 seconds. The increases in distance at maximum deceleration were similar to those found in initial reaction distance. Increases ranged from 47.3 to 137.2 feet (14.2 to 41.2 m) with an average of 66.5 feet (20.0 m). The flashers also increased the distance behind the slow-moving vehicle that the overtaking vehicle pulled out to pass (passer distance at lane change). The increases ranged from 30.6 to 94.8 feet (9.2 to 28.4 m) with an average increase of 55.7 feet (16.7 m).

Table 2.
Improvement in Safety: Flashers On

FLASHERS ON
INCREASE IN SAFETY

SITUATION / MOEs	30 mph				40 mph			
	2-LANE		4-LANE		2-LANE		4-LANE	
	STEEP	SLIGHT	STEEP	SLIGHT	STEEP	SLIGHT	STEEP	SLIGHT
IRD	+	+	+	+	+	+	+	+
TTC	+	+	+	+	+	+	+	+
DMD	+	+	+	+	+	+	+	+
PDLC	+	+	+	+	+	+	+	+

+ indicates an improvement in safety.

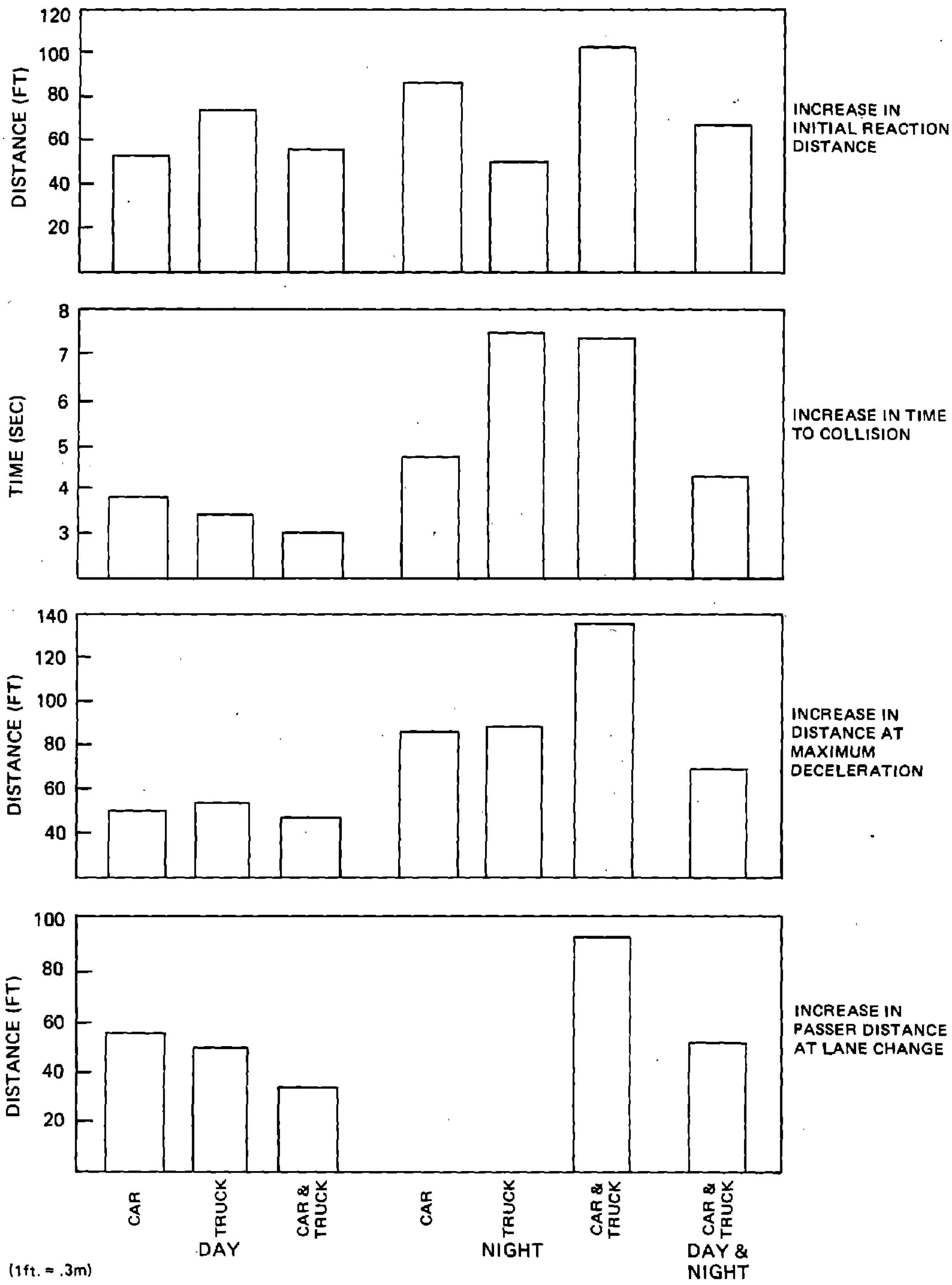


Figure 3. Effectiveness of four-way flashers: Increase in MOEs.

During the slow-moving vehicle study, data were collected on the passing behavior of overtaking vehicles at the two-lane sites. When flashers were displayed, it was found that fewer overtaking vehicles were involved in aborted passes; i.e., drivers started to pass but subsequently did not pass the slower moving vehicle.

A small-scale field study was conducted to determine the deceleration rates associated with various driving behaviors at the test sites. The purpose of the study was to approximate the driver response that typifies the behavior of drivers overtaking a slow-moving vehicle. The deceleration rates of a sample of three test vehicles were compared with the deceleration rates found in the slow-moving vehicle study. For the two-lane sites, the drivers of overtaking vehicles decelerated at a rate comparable to that produced by lifting completely off the accelerator. At the four-lane sites, the deceleration rates were comparable to those produced by lifting halfway off the accelerator.

Conclusions and Guidelines

Behavioral evaluations were conducted to determine the effect of four-way flashers on drivers overtaking a disabled vehicle and a slow-moving vehicle. When flashers are displayed on a disabled vehicle, it was found that overtaking vehicles tend to slow down sooner and slow down more. Although the absolute volume of the speed reductions were small, they were extremely consistent across the different test situations. Changes in behavior were apparent up to 1,200 feet (360 m) from the disabled vehicle. Flasher usage produces a change in awareness that promotes safety in the vicinity of the disabled vehicle. Apparently, the use of flashers on a disabled vehicle produces a change in the awareness of drivers approaching vehicles.

When flashers were displayed on slow-moving vehicles, it was found that overtaking traffic slows down sooner, slows down more gradually, and passes the slow-moving vehicle more cautiously.

Based on the research results, the following guidelines are presented:

- Disabled vehicles should display four-way flashers. Reflectorized warning triangles are nearly as effective as flashers, and should be used in long-term (greater than 2 or 3 hours) disabled situations. Flares are more effective than either flashers or triangles, and should be used in more hazardous situations.

- Slow-moving vehicles should display flashers when traveling less than 15 mph (24.2 kph) below the free-flow speed. The experimental results indicate that flashers had similar beneficial effects whether the slow-moving vehicle was going 15 or 25 mph (24.2 or 40.3 kph) less than the free-flow speed.

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