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15. Supplementary Notes

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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 I: Executive Summary, Volume III: Appendixes

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# I. BACKGROUND

## 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

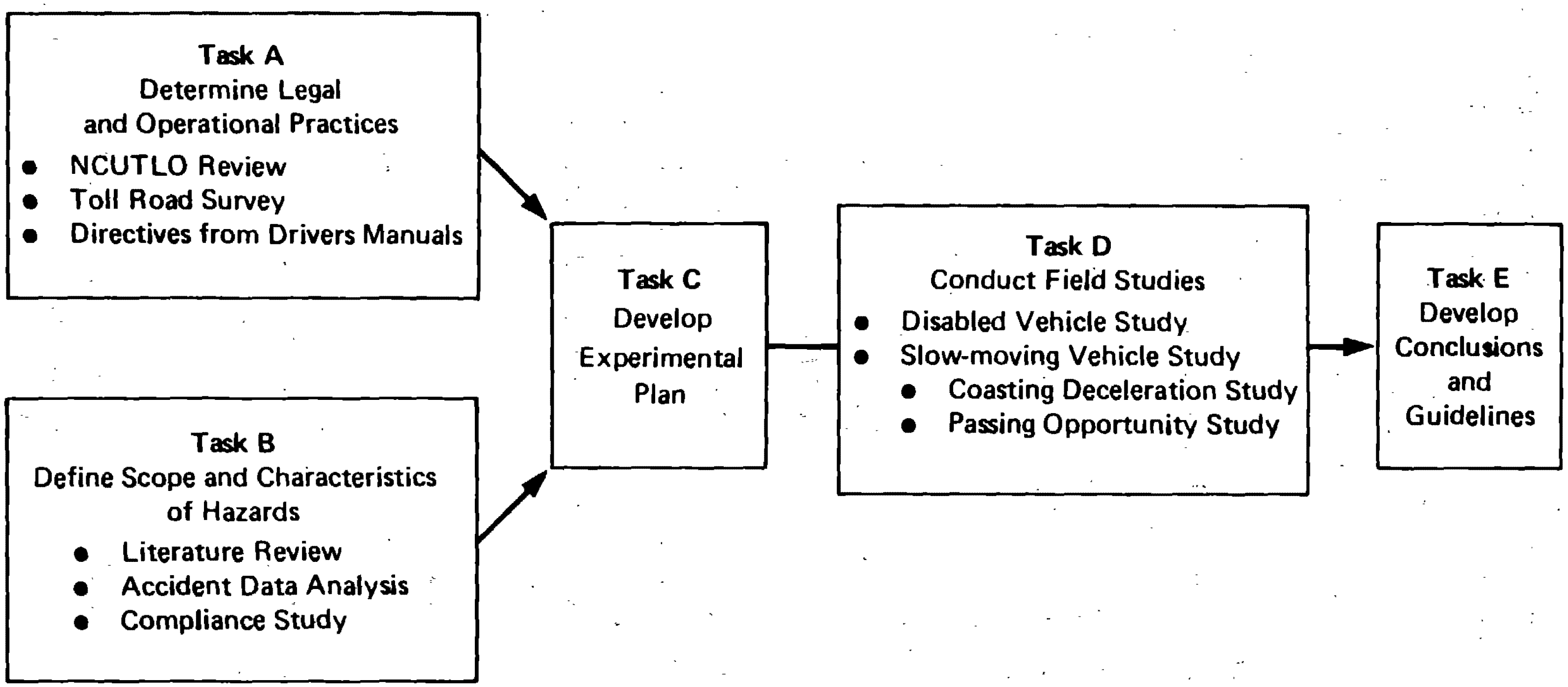


Figure 1. Project Tasks

study, In the second study a slow-moving vehicle was introduced into the traffic stream. Both studies were conducted on four section 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 report follows the basic organization of the project tasks. There are four major sections:

- Background and 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 second section 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 flahsers-on and the flashers-off conditions, a number of other conditions were evaluated. These included flares, warning triagles, headlights, and the presence of a "bystander" near the vehicle.

The third section presents the results and conclusions of the study on the effedts 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 fourth section is a brief statement of the conclusions of the research and a listing of suggested guidelines for the use of four-way flashers. The final section is the list of references.

The following section presents the literature review and describes several of the tasks undertaken to support the design and interpretation of the large-scale field evaluation of four-way flasher effectiveness. The section consists of six separate parts:

- Literature review
- Traffic regulations and legal issues
- Use of four-way flashers on tollroads
- Directions from driver manuals
- Analysis of selected traffic accident reports
- Compliance study.

The literature review describes some of the current research on the use of flashers in both the slow-moving and disabled vehicle situations. The section on traffic regulations and legal issues is a synopsis of a review of current regulations prepared by the National Committee on Uniform Traffic Laws and Ordinances (NCUTLO). The complete review is provided as a separate volume, Appendix A. The section on the use of four-way flashers on tollroads describes the results of a survey of tollroad directors regarding special instructions given to drivers. The information provided in state driver manuals regarding flasher usage is reviewed in the subsequent section. A discussion of traffic accidents occurring on upgrades is then presented. The final subsection describes the results of a field evaluation of the compliance to four-way flasher regulations in two states, New York and Pennsylvania.

## Literature Review

A literature search on this topic revealed that, until recently, no research study has yet investigated the behavioral response of drivers, in the field, to hazard warning lights. Recent work by Lanham, Lum, and Lyles (1979) and Lyles (1980) at the FHWA Maine facility has addressed this issue. Lanham *et al.* evaluated the effectiveness of various roadway signs and vehicle markings on slow-moving vehicles. Lyles considered the disabled vehicle situation. Since both of these efforts are very recent and evaluated only one roadway type (rural two-lane), they have not had much impact on rulemaking. The recommended, approved use of hazard warning lights, known as four-way flashers, is not uniform across all states. Some states, notably Pennsylvania and New York, prescribe the use of flashers for vehicles traveling slower than 40 mph (64.4 kph) on their interstates and turnpikes. Other states, such as California and Virginia, specifically prohibit the use of four-way flashers on any moving vehicle.

While there is little prior research dealing directly with this topic, many studies indicate the severity of a problem for which flashers may be the solution. The problem, simply stated, is how to reduce the number of collisions between vehicles traveling in the same direction. This problem includes both disabled vehicles stopped on roadway shoulders and vehicles colliding with slower-moving vehicles on the roadway. In a report on motor vehicle rear signal systems, the Century Research Corporation (1969) presents a finding initially stated by Nickerson, Baron, Collins, and Crothers (1968):

> *While it is sometimes maintained that hazard warning lights should be used only for a stopped vehicle and never when moving in traffic, it is felt that, in many cases, the distinction between "slow moving" and "stopped" is technical. The nature of the hazard is substantially the same and there is as much need for the warning signal in one case as in the other.*

No statistics document the number of accidents in which one vehicle was using its four-way flashers; and certainly no statistics demonstrate the number of accidents prevented or made less severe because one vehicle had its flashers on. In fact, there has been some concern that the use of flashers may "attract" approaching vehicles and increase the likelihood of a collision. This effect has been called the "moth phenomenon." In an effort to establish a "range" of accidents in which flashers might be a mitigating factor, a category of accidents could be selected in which the use of flashers is at least a theoretically pertinent factor. In 1976, rear-end collisions totaled 3,300,000 accidents, of which 80,000 were on rural roads (National Safety Council, 1977). On interstate highways, rear-end collisions are the most common multiple-vehicle accident type (Hosea, 1969; Vecellio, 1967). Hosea (1969) reported that 41% of all the fatal two-vehicle accidents on the interstate system were rear-end collisions. As traffic on the interstate system increases, these rear-end collisions may become even more frequent.

Of all motor vehicle accidents in 1976, 8.5% involved two vehicles traveling in the same direction; another 8.6% involved two vehicles heading in the same direction with one stopped in traffic (National Safety Council, 1977). Together, these two collision types represented 41.6% of all two-vehicle, nonintersection accidents. Mortimer and Sturgis (1975) report that vehicles stopping or stopped were . . . *most frequently involved in rear-end, injury-producing collisions on urban and rural roads,* (but) *vehicles that were moving straight were generally most involved in limited access highways.*

Similar results were found in a study of fatal car-into-truck collisions in Michigan and Texas (Minahan and O'Day, 1977).

The most common accident circumstances had the truck moving straight ahead and the car rear-ending the truck. The most frequent relative impact speed in these rear-end collisions was 30 to 40 mph (48.3 to 64.4 kph). Extrapolating from these Michigan and Texas data, the estimated annual national number of fatal car-into-truck accidents would be 571, with 308 of these being direct rear impacts.

In a study of automobile rear-end collisions, Solomon (1964) found that 47% of the accidents had a speed differential between the vehicles of more than 20 mph (32.2 kph); only 7% of the normal traffic traveled with such speed differences (see Figure 2A taken from Solomon). Other studies (Mitchell, 1966; Taylor, 1965; Research Triangle Institute, 1970) have concurred with this finding, suggesting that speed differentials between vehicles are the likely antecedent behavior in rear-end and other same-direction collisions. Results of the Research Triangle Institute study (1970) indicate that vehicles traveling more than 15.5 mph (25.0 kph) from the mean traffic speed were 12 times more likely to have a collision than were vehicles traveling within 5.5 mph (8.9 kph) of the mean speed. A vehicle pair traveling with a speed differential of 30 to 35 mph (48.3 to 56.4 kph) was 30 times more likely to be involved in a rear-end accident than a vehicle pair traveling with a speed differential of 15 mph (24.2 kph) or less.

Another way to conceptualize this speed differential problem is in terms of the greater monetary damage that results from rear-end collisions with greater relative speeds of the two vehicles involved. Figure 2B is derived from Vecellio's (1967) Ohio Turnpike accident study.

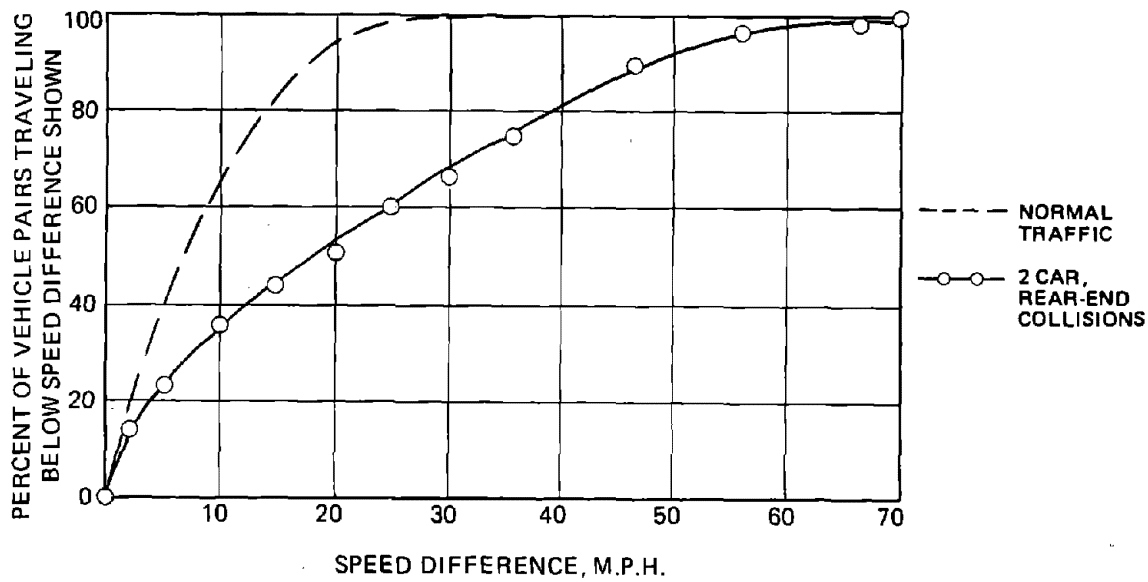


Figure 2A. Speed difference between passenger cars involved in two-car, rear-end collisions compared with normal traffic, day and night combined*

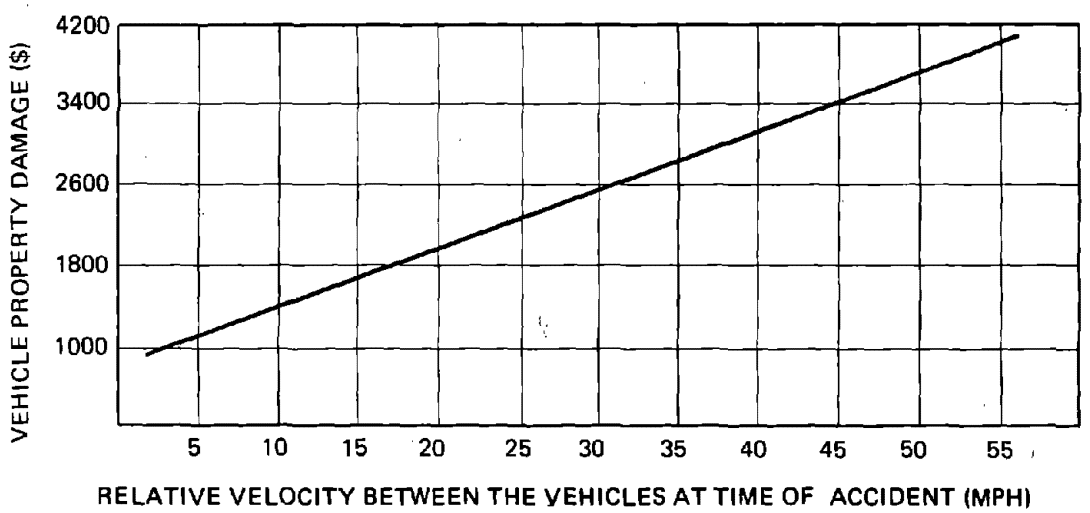


Figure 2B. Relative velocity-cost relationship for two-vehicle rear-end collisions, 1965**

1 mph = 1.6 kph

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*Taken from Solomon (1964)

**Taken from Vecellio (1967)

One factor in these rear-end collisions is that drivers have difficulty in perceiving speed differentials between their own vehicles and those they are approaching. An experiment on judgment of relative car velocity demonstrated that 19% of drivers would underestimate a 20 or 30 mph (32.2 or 48.3 kph) speed differential by as much as 10 mph (16.1 kph) (Olsen, Washsler, and Bauer, 1961). Table 1, from Mortimer and Sturgis (1975), shows the speed that "striking" and "struck" vehicles were traveling prior to rear-end collisions.

Mortimer *et al.* (1974) points out that more same-direction accidents occur on upgrades because more vehicle pairs travel at these larger speed differentials. In addition, trucks (particularly loaded trucks) lose more speed on upgrades than do automobiles (Firey and Peterson, 1962). Accordingly, trucks are disproportionately involved in rear-end collisions (Mortimer *et al.*, 1974). In data from the Ohio Turnpike, performance of vehicles on upgrades revealed this to be one of the more hazardous features of the Ohio Turnpike. This can be seen in Table 2, taken from Vecellio's 1967 study in which the tabular values of the "upgrade" column are larger than either the "level" road or "downgrade" columns.

Similar speed differences exist between loaded and unloaded trucks, so it is not surprising that in 53% of these upgrade collisions, the striking vehicle was a truck. In 88% of these cases, the truck ran into another vehicle (Vecellio, 1967). An earlier study (Eckhardt and Flanagan, 1955) examined accidents on the Pennsylvania Turnpike and produced similar results. They found that the single pronounced difference between car accidents and truck accidents was that trucks were involved in more accidents on the upgrade sections of the highway. Williston (1967) examined traffic speeds over a half-mile (0.8 km) of a

Table 1.

Percent Distribution of Reported Speeds of Struck and Striking Vehicles Prior to Impact in Crash Sample*

| Speed of Struck Vehicle - mph | Speed of Striking Vehicle - mph | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | 20-29 | 30-39 | 40-49 | 50-59 | 60-69 | 70+ | |
| 0- 9 | 6 | 18 | 24 | 15 | 8 | | 71 |
| 10-19 | 8 | 3 | 6 | | | 3 | 20 |
| 20-29 | 3 | | | | | 3 | 6 |
| 30-39 | | | | | | | 0 |
| 40-49 | | | | | | | 0 |
| 50-59 | | | | 3 | | | 3 |
| Total | 17 | 21 | 30 | 18 | 8 | 6 | 100 |

1 mph = 1.6 kph

*Taken from Mortimer and Sturgis (1975)

Table 2.

Truck-Car Accident Ratios for Rear-End Collisions on Level, Upgrade, or Downgrade Sections of Roadway*

| Year | Level | Upgrade | Downgrade | Total Number of Rear-End Collisions |
|---|---|---|---|---|
| 1960 | 0.58 | 1.23 | 0.60 | 225 |
| 1961 | 0.61 | 1.22 | 0.12 | 207 |
| 1962 | 0.67 | 1.13 | 0.56 | 217 |
| 1963 | 0.77 | 1.07 | 0.50 | 197 |
| 1964 | 0.60 | 0.69 | 0.71 | 299 |
| 1965 | 0.63 | 1.43 | 0.58 | 209 |

Tabular Value = Accidents Involving Trucks Divided by Accidents Involving Only Passenger Cars

*As presented in Vecellio, 1967

five percent grade on a Connecticut highway. Automobiles essentially maintained their speeds (a mean change of only 2 mph [3.2 kph]), but large trucks lowered their speeds from 53 to 33 mph (85.3 to 53.3 kph). The largest carriers, the tractor-trailers, suffered a speed dip of 50%, dropping from 54 to 26 mph (86.9 to 41.9 kph).

These data do not reveal if all drivers who could use their flashers in such a situation do in fact use them; nor do these data indicate whether flashers are the best safety response in this situation. The data can only confirm whether those highway situations which might cause drivers to use flashers are situations with serious accident potential.

So far, all traffic situations discussed have involved one moving vehicle being struck by another. There is yet another category of traffic safety to consider: disabled vehicles using flashers to signal their presence on the roadway shoulder or when stopped in a lane of traffic. While the latter situation is certainly a major traffic safety hazard, no research has yet investigated what effect a disabled vehicle using flashers in a traffic lane has on subsequent traffic. To conduct an experiment would be too great a hazard; general opinion is that all available signaling devices, including four-way flashers should be displayed. However, when the disabled vehicle has been moved to the shoulder, there is diverse opinion about whether flashers should be used.

Some regulatory agencies, such as the Bureau of Motor Carrier Safety (1974), suggest the use of flashers only until other emergency signaling devices can be deployed. Certain states, like Maryland and Oregon, encourage flashers for vehicles on the shoulder. The opposite opinion--that the use of flashers on vehicles off the roadway poses a greater hazard to traffic than it provides in safety in terms of alerting drivers to the vehicle on the shoulder--has certain appeal but is not incorporated into any state regulations. There has been little research on this question. Allen, Miller, and Short (1973) used radar to monitor the speed of vehicles going past a simulated disabled car parked on the shoulder. Of interest were the effects of emergency flares, triangular distress signals, warning flags, and the motorist from the disabled vehicle on altering the speed of traffic going past the disabled vehicle. While this experiment tested the applications of the alternative emergency devices and not the flashers, the testing situation was certainly relevant. The results of this experiment were notable, for no combinations of flares and triangles had any significant effect on traffic during the daytime over that provided by the vehicle itself. At night, however, flares were more effective at slowing traffic and were detected sooner than other devices. Lyles (1980) evaluated the effects of warning triangles and four-way flashers on motorists approaching a disabled vehicle parked on the shoulder. He found that flashers were an effective means for warning approaching motorists of the presence of a disabled vehicle. The evidence for gaining additional speed reductions with warning triangles was not as conclusive.

In another experiment, Jehu (1962) compared emergency triangles with portable warning lights. His results were similar to those of the previous study. During sunlight hours, the portable light was deemed "totally inadequate"; in fact, the container that held the light could actually be seen before the light itself. While the triangle was no more visible during these hours, its advantage lies in its ability to convey a warning quickly. At night, drivers traveling 50 mph (80.5 kph) could see the triangle from 900 to 750 feet (270 to 225 m) away--a distance considered adequate for the drivers to react appropriately. The warning lights could be seen at night from greater distances, even when used at low intensity. Also compared in the experiment were reflectorized, fluorescent, and yellow triangles, the most effective warning triangle being partially reflectorized and partially fluorescent.

In the United Kingdom, following the introduction of regulations requiring fluorescent and reflective stripes on the rear of trucks, accidents in which vehicles ran into the rear of parked trucks were reduced by almost 29%. The number of collisions into the rear of moving trucks was reduced by 7%. In each case, the accident reductions were greater at night (United Nations Economic and Social Council, 1973).

The inclusion of flashers in these experiments might have resolved whether these lights minimize safety hazards when one vehicle is off to the side of a roadway. The larger question, though, it whether using flashers in the vehicle-off-the-road situation detracts from their effectiveness when they are used by slow-moving vehicles. Does the use of flashers in one situation cause driver confusion when they are used in other situations? Or is the danger of an ambiguous interpretation much smaller than the safety gain from using flashers in situations where a driver should exercise special caution in approaching and passing other vehicles?

Just as flares, warning flags, and emergency triangles have been proposed as alternate devices to four-way flashers for disabled vehicles, several researchers have tested alternative warning aids for slow-moving vehicles. One study (Francis, 1971) attempted to determine if a warning symbol--a fluorescent red hollow triangle with 4-inch (10.2-cm) amber flashing lights on each corner--could help prevent rear-end collisions. The results showed that drivers following trucks with a warning triangle changed lanes sooner on their approach to the truck and passed it at a slower speed than they did when the symbol was not present. Quite obviously, this kind of symbol has more relevance for vehicles traveling at slower speeds than it does for those moving at standard highway speeds with occasional slowdowns, on upgrades, or in some particular emergency situation. In other words, the driver usually needs more advance knowledge than such a warning device provides.

All the studies cited have dealt with the behavior of drivers responding to vehicles flashing some emergency message with their hazard warning lights. Researchers have also investigated the appropriate performance requirements of flashers. Post (1976) has demonstrated that flash rates of between 40 and 180 cpm were . . . *acceptable when combined with a reasonable duty cycle that insured an adequate level of intensity and on/off light output contrast.* Other relevant findings from this study include: *Flash rates of 120-180 cpm produced shorter response times than flash rates of 20-60 cpm. 'On' times of 30-80% did not prove statistically . . . different response times for flash rates of 20-180 cpm. Amber . . . was found to be advantageous in eliciting short response times in the hazard mode and resulted in few missed signals at night.*

One problem in determining appropriate light intensity requirements is that lamps which are adequately visible during the day will be too intense, and cause glare discomfort at night (Mortimer, 1970). The current standards, as issued by Federal Motor Vehicle Safety Standards (FMVSS), designate that the turn signal lamps (which are the hazard lights) shall be between 200 cp and 800 cp for amber and between 80 cp and 300 cp for red.

The SAE standards recommend 8.0 square inches (52 $cm^2$) (in lieu of the previously legally mandated 3.5 square inches [22.75 $cm^2$]) for the size of rear signal lamps on passenger cars. These rear signal lamps may be amber, yellow, or red.

The relative effectiveness of red versus amber lights needs to be mentioned. Mortimer *et al.* (1973) found that red was somewhat more effective than amber in daytime use. At night, though, amber proved clearly more effective than red.

## Traffic Regulations and Legal Issues Pertaining to Hazard Warning Lights

The National Committee on Uniform Traffic Laws and Ordinances (NCUTLO) prepared a review of the current status of state laws and federal regulations concerning vehicle hazard warning lights in the content of the provisions of the Uniform Vehicle Code. There were substantial differences among the various state laws in provisions dealing with the use of flashers. The entire NCUTLO review is included as Appendix A (Volume III). The summary of legal issues is presented below.

### Use of the Lights

The most significant issue involves use of vehicle hazard warning lights on a moving vehicle. Currently, use of vehicle hazard warning lights on a moving vehicle is prohibited as to any vehicles subject to the Federal Motor Carrier Safety Regulations, regardless of where they are operating.

The basis for the current Bureau of Motor Carrier Safety position is that highway safety will be best served by reserving the four-way flashing signal to denote a specific kind of hazard, a stopped vehicle. It is questionable whether this position can ever be effectively implemented by the Bureau. Vehicle hazard warning lights are now present on most vehicles. The authority of the Bureau, and its ability to preempt state laws, extends to only a small part of the total vehicle population. If most vehicles can and do display four-way flashers to denote a moving vehicular hazard, it is very doubtful that the Bureau's regulations can effectively reserve the four-way flashing signal to denote a stopped vehicle hazard only. Use of four-way flashers on a moving vehicle is required under certain conditions by one state, and one state tollroad authority. Such use is specifically allowed by 32 states, and another 11 do not specifically prohibit it. Also a number of states now require or authorize the use of four-way flashers on various kinds of highway maintenance and snow removal vehicles, pilot vehicles for oversized loads, tow trucks, mail delivery vehicles, and some others. Only eight states have laws that agree with the Bureau's position prohibiting the use of four-way flashers on moving vehicles.

There is need for a broad-based policy decision regarding the use of vehicle hazard warning lights. A policy that could be uniformly implemented in all jurisdictions and for all vehicles would be very desirable.

If the broad-based policy decision is to prohibit the use of vehicle hazard warning lights on moving vehicles, the following should be done:

1. The Federal Motor Carrier Safety Regulations should be amended to clearly specify such a prohibition.

2. The Uniform Vehicle Code and the laws of 42 states and the District of Columbia should be revised to incorporate such a prohibition.

3. Pennsylvania and the New York Thruway Authority should repeal their requirements for use of the lights on certain moving vehicles.

4. All state laws providing for required or permissive use of four-way flashers on moving farm vehicles or special purpose vehicles should be amended, substituting some other lighting device for this purpose.

If the broad-based policy decision is to permit use of vehicle hazard warning lights on moving vehicles whenever the driver is giving warning of a vehicular hazard, the following should be done:

1. The Federal Motor Carrier Safety Regulations should be amended to permit such use of the lights. A specific amendment would be desirable to reverse the effects of the Bureau's current interpretation.

2. The laws of eight states should be amended to permit use of the lights on a moving vehicle.

If the broad-based policy decision is to require the use of vehicle hazard warning lights on slow-moving vehicles or under other specific circumstances, the Federal Regulations, the Uniform Vehicle Code, and the laws of almost all the states would need to be amended to implement such a policy.

<u>Validity of State Law</u>

A second issue involves the validity of all the state laws in light of the Federal Motor Vehicle Safety Standards. While only the New Mexico law is in conflict with the Federal Standards, the extent of preemption under the federal law is very unclear. This issue does not have great significance in terms of vehicle hazard warning lights, but is important in terms of the states' overall role in regulating vehicle equipment. Although judicial decisions may ultimately define the respective roles of the federal and state governments in this area, Congressional amendment of section 103(d), the preemption section of the National Traffic and Motor Vehicle Safety Act, would be very desirable to alleviate the confusion caused by the current language.

## Use of Hazard Warning Lights on Toll Highways

This section presents a compilation of special instructions given to drivers on the toll highways of the country. As is evident from Table 3, the authorities of most of these roads do not issue any special instructions to drivers. This information was organized with the help of the National Committee on Uniform Traffic Laws and Ordinances from a mail survey of the directors of the toll highways.

Only three states, New York, Pennsylvania, and Rhode Island, use signs to specify that slow-moving vehicles should display flashers. In New York and Pennsylvania, the sign message is "Trucks Under 40 mph Use Flashers." The signs are posted on grades of +3% where there is likely to be a speed differential between cars and trucks. In Pennsylvania, the upgrades are not posted if there is a separate climbing lane. In Rhode Island, signs are used where the speed of vehicle operation is less than 25 mph (40.3 kph).

None of the facilities surveyed provide instructions on the toll ticket for the use of four-way flashers. Two states, Indiana and New Jersey, provide instructions on the toll ticket with regard to becoming disabled, but neither state specifies that flashers should, or should not, be displayed.

Table 3.

Survey on Directed Use of Vehicle Hazard Warning Lights by Toll Highway Authorities

| | | | Instructions on Toll Tickets | |
|---|---|---|---|---|
| State | Road Sign? | Sign Message | For Use of Four-Way Flashers | For Disabled Motorists |
| Florida | No | Does not apply | No | No |
| Illinois (1)* | No | Does not apply | No | No |
| Indiana (2)* | No | Does not apply | No | Yes (3)* |
| Kansas | No | Does not apply | No | No |
| Maine | No | Does not apply | No | No |
| Massachusetts | No | Does not apply | No | No |
| New Jersey Highway Authority (1)* | No | Does not apply | No | No |
| New Jersey Turnpike Authority | No | Does not apply | No | Yes (4)* |
| New York (5)* | Yes | (6)* | No | No |
| Ohio | No | Does not apply | No | No |
| Pennsylvania | Yes | (6)* | No | No |
| Rhode Island (1, 7)* | Yes | (7)* | No | No |
| Texas (1)* | No | Does not apply | No | No |
| West Virginia | No | Does not apply | No | No |

*Explanation of numbered items appears on the following page.

Explanation of Numbered Items in Table 3

(1) Toll tickets not issued on this highway.

(2) Evidence supporting directive from "very low accident rate involving personnel and equipment."

(3) Steer off traveled portion of road; raise hood and tie handkerchief to radio antenna; don't stand or walk in moving traffic lane.

(4) Park disabled vehicle on right shoulder--stay with vehicle and await police aid.

(5) Evidence supporting directive from "accident history for the years 1954 through 1963 (which) showed a clustering of rear-end accidents involving trucks at certain upgrades."

(6) "TRUCKS UNDER 40 MPH USE FLASHERS"; posted at grades of +3% where speed differentials between trucks and cars will be significant. Not posted in Pennsylvania if a climbing lane exists.

(7) Signs used when vehicle operation is at speeds of less than 25 mph (40.3 kph). (Respondent did not specify sign content.)

## Directives From Driver Manuals

The following information has been compiled from a survey of current driver manuals of the 50 states and the District of Columbia. In certain instances this information is at variance with actual state laws because of the difficulty of translating legal codes into language understandable by the user or the lag period in assimilating legal changes into the manuals. In a few instances, unexplained discrepancies occur.

### Four-Way Flashers

A review of the 51 current driver manuals was first made to determine which ones mention the use of four-way flashers:

- 51% (26) of the states do not mention the use of four-way flashers
- 30% (15) recommend or suggest using four-way flashers when car is disabled
- 22% (11) recommend using four-way flashers in emergencies.

Moving Vehicles. Very few states mention the use of flashers by moving vehicles:

- 4% (2) recommend the use of flashers on moving vehicles. Vermont recommends their use to drivers traveling under 40 mph (64.4 kph) on an interstate. Washington recommends their use by trucks and buses to warn other drivers of a traffic hazard, of a truck stopped on the road, or if they are traveling at a much lower speed than other vehicles.

- 4% (2) permit the use of flashers on moving overweight and oversized vehicles traveling under special permit.

- 4% (2) specifically mention that flashers should <u>not</u> be used on moving vehicles.

<u>Warning Triangles for Slow-Moving Vehicles</u>

Information on the slow-moving vehicle (SMV) triangle in the driver manuals was also tabulated:

- 37% (19) require the triangle on slow-moving vehicles (there was rarely any mention of exactly what is considered "slow moving")

- 33% (17) tell prospective drivers what the triangle is and how it is used, but make no mention of it being required

- 29% (15) do not mention the SMV triangle at all.

Table 4 summarizes the flasher usage recommendations from the survey of driver manuals. Figure 3 is an outline map showing the states that discuss the SMV triangle in their driver manuals. Figure 4 is an outline map showing which states specify flasher usage under various situations.

Table 4.

Directives from State Driver Manuals on Use of Vehicle Hazard Warning Lights

| Flasher Use | Mandatory & Recommended | | Suggested & Permitted | | Prohibited | | Total* | |
|---|---|---|---|---|---|---|---|---|
| | % | N | % | N | % | N | % | N |
| Emergency | 22% | 11 | | | | | 22% | 11 |
| Disabled Vehicle | 22% | 11 | 8% | 4 | | | 29% | 15 |
| Headlight Failure | | | 10% | 5 | | | 10% | 5 |
| Unattended or Parked Vehicle | 8% | 4 | 2% | 1 | | | 10% | 5 |
| Loading in a No Parking Zone | 2% | 1 | | | | | 2% | 1 |
| Moving Vehicle | 4% | 2 | 4% | 2 | 4% | 2 | 12% | 6 |
| No Mention of Flashers in Manual | | | | | | | 51% | 26 |

N = 51; 50 states and the District of Columbia.

*The total does not add up to 51, or 100%, because some states mentioned more than one use for four-way flashers.

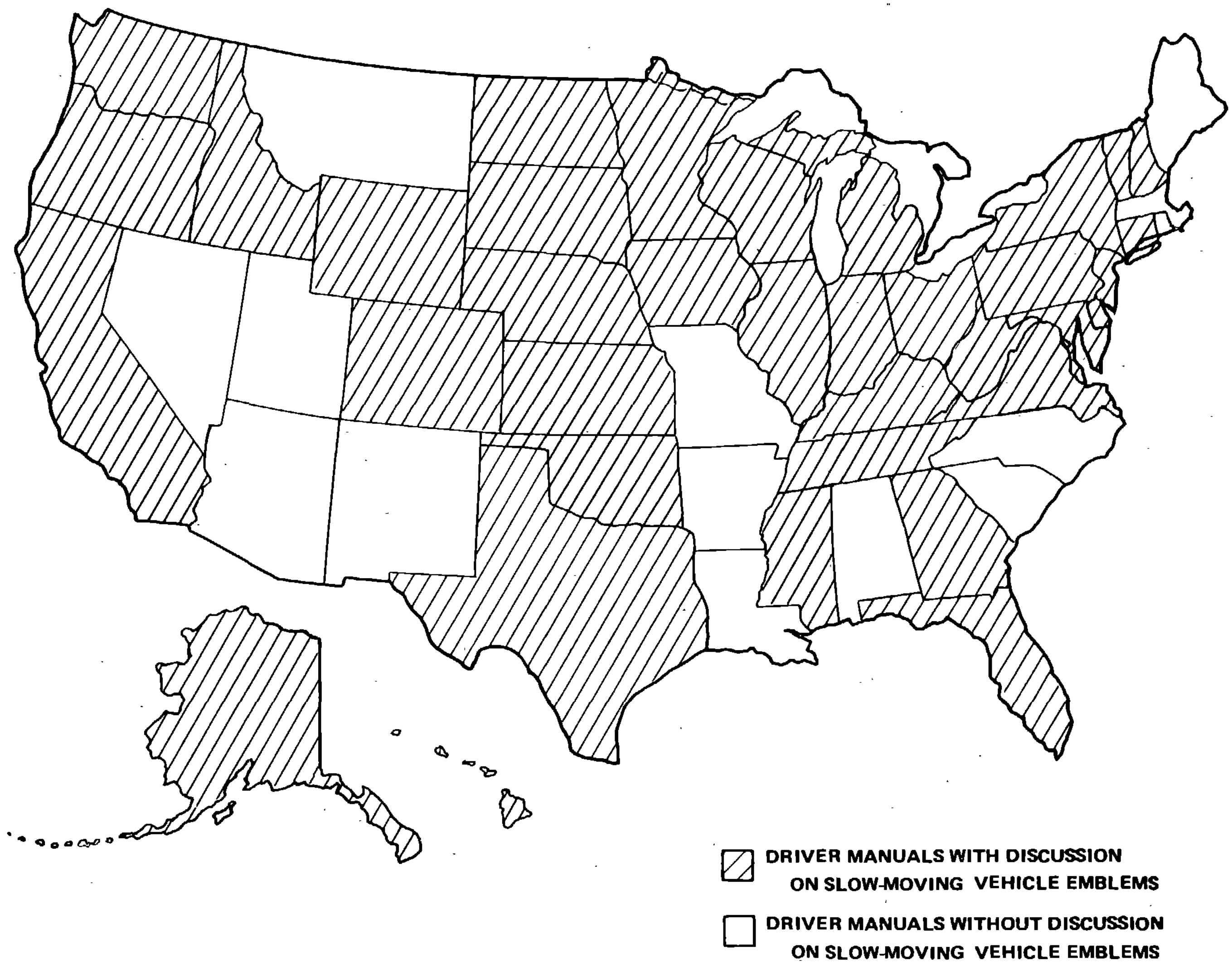



Figure 3. States whose drivers manuals discuss triangular warning emblems for slow-moving vehicles.

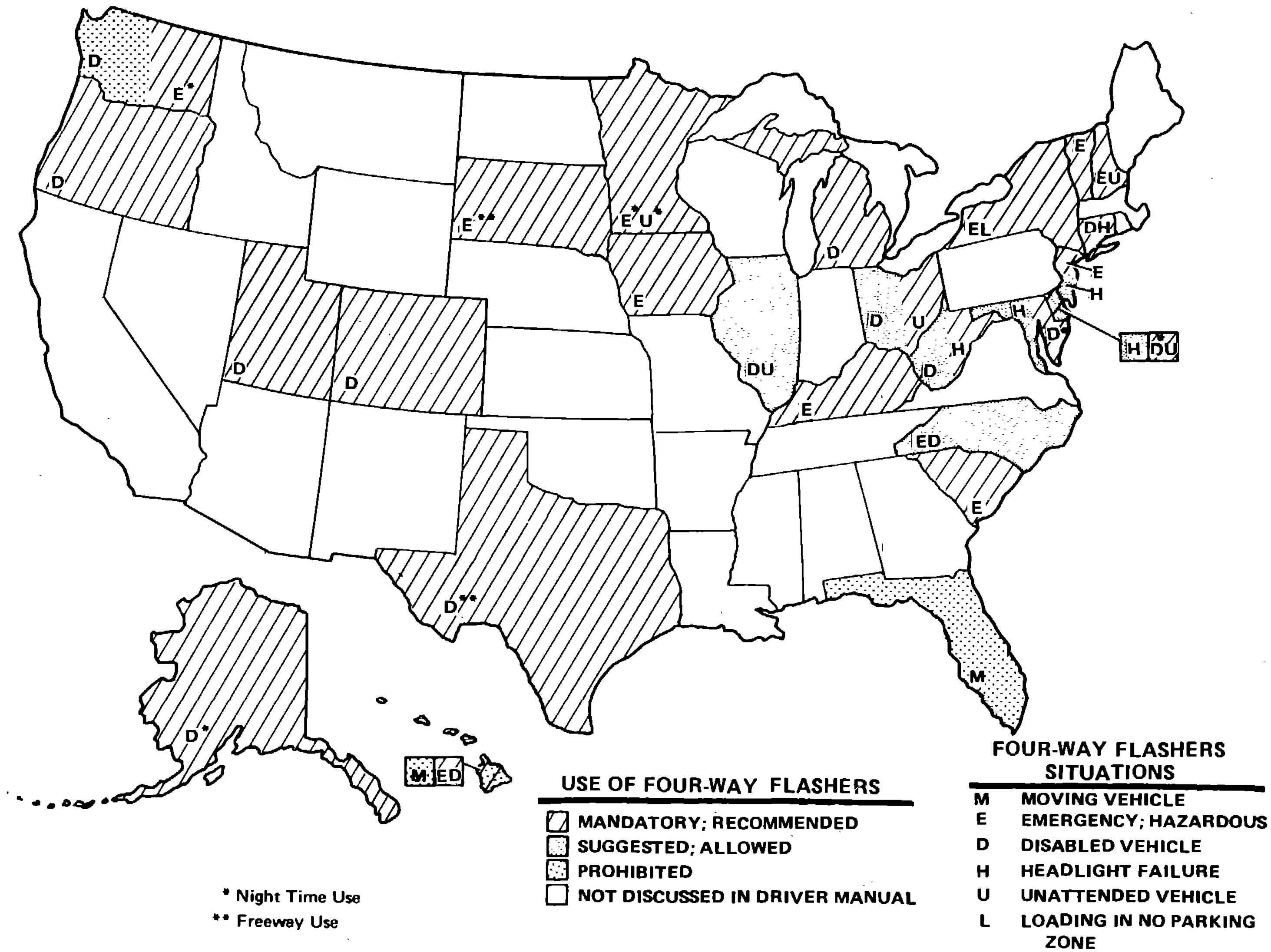



Figure 4. State driver manual instructions for use of four-way flashers

## Analysis of Traffic Accident Reports

Evidence presented in the literature review indicates that accidents on upgrade road segments belong to a class of accidents in which driver misinterpretations of relative speeds among vehicles could have been a significant causal agent. Therefore, the use of warning flashers in these situations might have a safety promoting effect. The following information was obtained from police reports of accidents occurring on hilly sections of rural highways in North Carolina and Virginia. The police reports provide a framework for interpreting the comparative dangers of these accidents.

Eight sites, covering 133 miles (214.1 km), were examined in North Carolina. Ten sites, covering 127 miles (204.5 km), were examined in Virginia. The accident reports in North Carolina were from the years 1975 to 1977; in Virginia, from 1973 to 1976.

Of the 144 accidents at the North Carolina sites, 50 were on an upgrade; 14 of these 50 may have involved misreadings of differential vehicle speeds. The others were single-vehicle accidents or were clearly unrelated to the type of incidents that four-way flashers might prevent. The police reports do not indicate whether any of the involved vehicles used four-way flashers. The intent of this section is to compare those accidents that <u>might</u> have been prevented by flashers to other on-grade accidents. The percentage of these "target" accidents occurring on icy, wet, or snow-covered roads is 36%. This is very close to the percentage of all on-grade accidents occurring under these conditions (38%) and to the percentage of all on-grade accidents occurring on icy, wet, or snow-covered roads (32%). About 14% of nighttime accidents are suspected of being relevant to four-way flasher usage. The police estimates of average property damage in these accidents were less than the amount of estimated damage for all uphill accidents ($900 versus $1,205), which in turn is less than the estimated average cost of all accidents occurring on these hills ($2,164).

Similar comparisons were extracted from Virginia police accident report data. It should be noted again that those accidents in which flashers may have had a preventive effect are of specific interest. The report forms do not indicate whether flashers were used. In fact, state law in Virginia precludes the use of flashers on moving vehicles. Reports from 10 hillside sites were examined. These included reports of 126 accidents, of which 30 were on icy or wet roadways; while 47 occurred at night. As in the North Carolina data, fewer than half of the accidents (42 out of 126) were uphill incidents. Twelve percent of these uphill accidents (a total of 5) were determined to be in the special interest category. None of these latter accidents occurred on icy or wet roads, and only one occurred at night. (This compares with 12 icy or wet road accidents of all uphill accidents and 16 nighttime uphill accidents.) The average property damage estimates of the special interest category was $1,580. For all uphill accidents the figure was $1,171; and for all the accidents at these sites the figure was $1,106. These figures are summarized in Table 5.

It is apparent that the accidents that might be affected by flasher usage (the target group) are not appreciably different from other accidents occurring on the same roadway. If anything, they are less likely to occur during bad weather or at night. The property damage estimates from Virginia and North Carolina are at odds. Therefore, it is not possible to draw any conclusions about the relative severity of the various accident groups.

Table 5.

Number, Percentage, and Property Damage Estimates of Accidents in North Carolina and Virginia

| | North Carolina | | Virginia | |
|---|---|---|---|---|
| | N | % | N | % |
| Total Accidents | 142 | 100% | 126 | 100% |
| Bad Weather Accidents | 46 | 32% | 30 | 24% |
| Nighttime Accidents | 52 | 36% | 47 | 37% |
| Property Damage, Average | $2,164 | | $1,106 | |
| Uphill Accidents | 50 | 100% | 42 | 100% |
| Bad Weather Accidents | 19 | 38% | 12 | 29% |
| Nighttime Accidents | 16 | 32% | 16 | 38% |
| Property Damage, Average | $1,205 | | $1,171 | |
| Target Accidents* | 14 | 100% | 5 | 100% |
| Bad Weather Accidents | 5 | 36% | 0 | 0% |
| Nighttime Accidents | 2 | 14% | 1 | 20% |
| Property Damage, Average | $ 900 | | $1,580 | |

*Target accidents are those that might have been prevented by the use of flashers on the slow-moving vehicle.

## Compliance Study

On the Pennsylvania Turnpike and the New York State Thruway, permanently posted road signs instruct truck drivers proceeding at less than 40 mph (64.4 kph) to use their four-way flashers. Typically, these signs are posted at the beginning of long and/or steep upgrade sections of roadway. This prescribed use of flashers is diametrically opposed to that of several states (e.g., California and Virginia), in which the use of flashers by moving vehicles is strictly prohibited.

The purpose of this study was to measure the degree of driver compliance with the sign's instructions. Seven sites were chosen for observation. Six were in New York and one was in Pennsylvania. Fewer sites were available in Pennsylvania where the observer could unobtrusively measure vehicle speed and record compliance at or near the hillcrest. Table I-6 lists the sites using the Thruway or Turnpike mileage designations as site names. More data were collected at those sites steep enough to slow most truck traffic to 40 mph (64.4 kph) or less. At one posted site in particular, NY 81 SB, traffic slowed considerably less than at other sites. Indeed, three sites did not post a warning sign but truck traffic slowed to a degree greater than that on NY 81 SB. Table 6 also lists the sites that were not posted with warning signs as well as the average speed of all truck traffic at each site. (The definition of "trucks" was limited to tractor-trailers, excluding step vans, pick-ups, and other small, single-unit vehicles.) These average speeds represent a *de facto* measure of difficulty of ascendance. The slower the average speed, the longer and/or steeper was the hill.

A total of 1,519 truck speeds were measured with the use of a radar gun. The speed measures and compliance data were taken

TABLE 6.

Percentage of Trucks Going 40 mph or Less

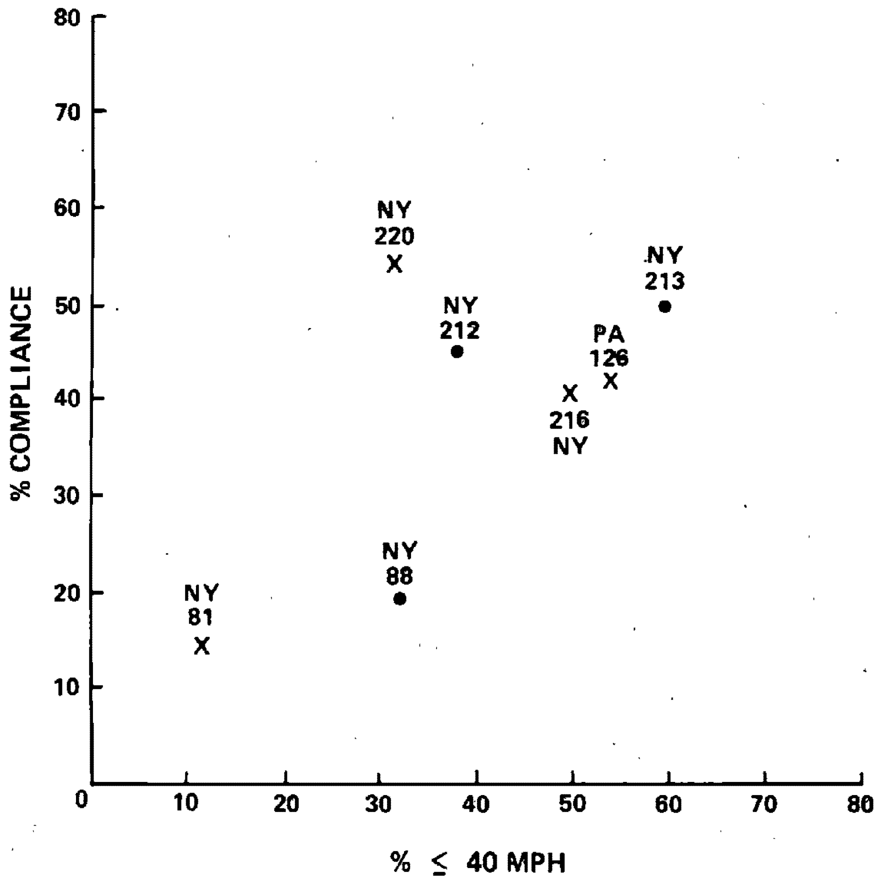
| Name of Site (State/Milepost) | | Mean Speed of All Trucks (mph) | Percent of Trucks Going 40 mph or Less | Warning Signs |
|---|---|---|---|---|
| NY | 213 | 39.58 | 61 | Not Posted |
| PA | 126 | 40.46 | 53 | Posted |
| NY | 216 | 41.50 | 50 | Posted |
| NY | 220 | 45.78 | 33 | Posted |
| NY | 88 | 45.97 | 33 | Not Posted |
| NY | 212 | 46.05 | 38 | Not Posted |
| NY | 81 | 50.84 | 11 | Posted |

1 mph = 1.61 kph

at the hillcrest. Of this number, 701 trucks were traveling at 40 mph (64.4 kph) or less; 916 were monitored during the day and 603 at night. Also, 1,073 trucks were sampled at the sites posting the warning sign and 446 were monitored at the unposted sites.

At all sites and over night and day conditions, 61.6% of the 701 trucks in the sample of slow-moving vehicles complied with the direction to use flashers. There was very little difference in compliance by truck drivers proceeding slowly up hills that were posted (61.48%) and hills that were not posted (61.97%). This clearly indicates that drivers interpret the message of the signs to apply statewide and not only to those hills where the signs were actually posted.

Of the trucks going less than 40 mph (64.4 kph), the 61.6% that used flashers averaged 32.1 mph (51.7 kph) in uphill speed. The group that did not use flashers (but were obliged to under the instruction of the sign) averaged 36.3 mph (58.4 kph). This indicates that the group that did not display flashers was probably going 40 mph (64.4 kph) or more for a longer proportion of the grade. This difference in speeds was statistically significant at a level of $p<.01$, indicating that the slower truck drivers are proceeding up a hill, the more likely they are to comply with the directive. Figure 5 portrays this same effect in a slightly different fashion; this graph shows the percentage compliance of slow-moving vehicles as a function of the percentage of all trucks moving at 40 mph (64.4 kph) or less. Compliance is less on hills where a greater percentage of traffic is moving faster than 40 mph (64.4 kph). The need to use flashers would seem to be greater when any single truck is traveling slower than other traffic, but this is not the case. The more trucks that are proceeding slowly, the more likely it is that any single slow-moving truck will use its flashers.




X indicates sites with warning signs
o indicates sites without warning signs
Abbreviations and numbers shown indicate state and milepost marker

Percentage of trucks traveling ≤ 40 mph vs. percentage of flasher usage.

1 mph = 1.6 kph

Figure 5.

Another feature of the problem is the relative use of flashers as a function of lighting conditions. The percentage of compliance by drivers of slow-moving vehicles increases during the night hours. The daytime compliance is 58.5%; the nighttime compliance is 65.3%. The greater compliance at night is reasonable because it is more difficult to judge relative speeds at night. Thus, the need for truck drivers to indicate unexpected changes in speeds is accomplished through the use of flashers.

A compliance rate of 61.5% to posted requirements to display flashers when traveling less than 40 mph (64.4 kph) is not particularly impressive. The fact that compliance is even lower at sites where fewer vehicles are going less than 40 mph (64.4 kph) is particularly discouraging. Flashers are not being used where they might be most effective--at locations with higher speed differentials. Truck drivers are, no doubt, unaware of the inconsistencies between the regulations of the various states. Compliance, or the lack of it, is probably influenced by the driver's perception of the confusion revolving around flasher use regulations. This underscores the need for standardizing the flasher use requirements.

# RESEARCH DESIGN AND METHODOLOGY

This section describes the research design and methodology developed to evaluate the effects of four-way flashers on the behavior of traffic approaching either a disabled vehicle or a slow-moving vehicle. The basic design was to simulate both the slow-moving and the disabled vehicle conditions and to monitor the behavior of approaching drivers.

As is the case with any experimental design, the first task is to specify the independent and dependent variables. A methodology is then developed to determine the effect (degree of change) that the independent variables have on the dependent variables. This section addresses three key topics:

- Independent Variables
- Dependent Variables
- Methodology

Although the study of the disabled vehicle condition and the study of the moving vehicle condition are two separate issues, the research designs for the two studies have many common elements. In discussing the three topics listed above, the elements common to both studies will be described first. Then those elements unique to each condition will be introduced.

## Independent Variables

Independent variables are those factors which are selected or changed in order to produce changes in the dependent variable. In a real-world evaluation of driver behavior, it is necessary to select and/or control a vast number of variables if the factors that are producing changes in the dependent variable are to be isolated. There were essentially three types of independent variables that were considered in this research design.

- Site-Specific Variables
- Vehicle-Specific Variables
- Condition-Specific Variables.

The first two types were common to both the disabled vehicle study and the slow-moving vehicle study. The last type of variable is unique to the disabled and slow-moving test conditions.

### Site-Specific Variables

A vast number of environmental characteristics influence the way a driver reacts to any given situation. By conducting the experiments at a limited number of locations most of these characteristics can be controlled.

Since four-way flashers are most often used by slow-moving vehicles on an upgrade, it was appropriate that the test locations be upgrades. Since driver behavior, particularly deceleration, is influenced by the degree of upgrade, it was also appropriate to have different degrees of upgrade as an experimental variable. Driver behavior is also affected by roadway characteristics such as roadway width and number of lanes. Drivers on a four-lane highway (two lanes in one direction) have considerably more latitude in how they can react to either a slow-moving or a disabled vehicle. The number of lanes is clearly an experimental variable of interest.

Ambient lighting clearly affects driver behavior. Also, artificial lights, including flashers, are less visible during the day than they are at night. Although the transient periods, dawn and dusk, are of interest, there is typically not enough time or funds to collect sufficient data. Therefore, another experimental variable is the comparison of daytime and nighttime conditions. These three site specific variables were combined to produce eight experimental test situations that were controlled for in this study:

Day, two-lane, steep grade
Day, two-lane, slight grade
Day, four-lane, steep grade
Day, four-lane, slight grade
Night, two-lane, steep grade
Night, two-lane, slight grade
Night, four-lane, steep grade
Night, four-lane, slight grade.

Vehicle-Specific Variables

The characteristics of either a slow-moving or disabled vehicle may influence the behavior of an approaching driver. The type of vehicle, its conspicuity, speed, and location are all potential variables of interest. The type of vehicle that a driver is approaching may affect his/her behavior. For example, a tractor-trailer is likely to elicit different responses than an automobile. Therefore, two test vehicles - a tractor-trailer and an automobile - were used in the two field experiments.

The conspicuity of a vehicle may also affect the approach behavior of drivers. Indeed, the stated purpose of this research was to determine if the presence of four-way flashers influences the behavior of approaching traffic. The most crucial experimental variable, then, is the presence or absence of flashers. In recent years amber taillight lenses have become increasingly popular. Although commonplace in Europe, they have not yet replaced red lenses on domestic automobiles. Laboratory research has suggested that amber flashers are more effective at night. Thus, another variable of interest was the comparison of red and amber flashers. Since amber flashers are generally available only on automobiles, the red versus amber conditions were only evaluated on the test car. These three vehicle-specific variables were combined to produce five experimental test conditions in this study:

Car, flashers off
Car, flashers on, amber
Car, flashers on, red
Truck, flashers off
Truck, flashers on.

One obvious vehicle-specific variable is whether the vehicle is moving. The last two groups of independent variables are presented relative to the disabled vehicle condition and the slow-moving vehicle condition.

Condition-Specific Variables

A number of characteristics of the disabled vehicle were of interest. The major question involved determining which characteristics or features tend to improve safety. Specifically, there was a desire to determine which features cause approaching drivers to be more cautious. Highway flares and reflectorized warning triangles are often used to mark a disabled vehicle's location. Are they effective? Several placement procedures have been suggested for flares and warning triangles. Are there any differences in the relative effectiveness of these placements? Do drivers notice discrete cues such as the presence of a bystander and respond differently? Does the sex of the bystander affect driver behavior? Does raising the hood or the trunk of the disabled vehicle have any intrinsic meaning to approaching drivers and cause them to modify their behavior? At night, when a driver's vehicle becomes disabled and he/she pulls onto the shoulder, should he/she leave his headlights (parking or running lights) on?

Each of these questions regarding the characteristics of a disabled vehicle raises an important question that was considered in the research design. A total of ten disabled vehicle conditions were identified:

No features, disabled vehicle only
(car and truck, day and night)
(Headlights (parking lights or running lights on)
(car and truck, night only)
Flares, standard placement[1]
(car and truck, day and night)
Flares, tapered placement[1]
(car and truck, day and night)
Triangles, standard placement
(car and truck, day and night)
Triangles, tapered placement
(car and truck, day and night)
Bystander, female
(car, day only)
Bystander, male
(car, day only)
Raised Hood
(car, day only)
Raised Trunk
(car, day only)

Each of these conditions was tested in the flashers-on and the flashers-off conditions to determine if any synergistic effects were apparent. Also, each condition was tested at each of the four test sites.

---

[1]The various warning device placement procedures are described in detail in the discussion of the experimental results in Sections II and III.

The major issue of the slow-moving vehicle study was to determine if any improvement in safety was produced by slow-moving vehicles using their four-way flashers. The next issue is to define a slow-moving vehicle. How slow is slow? It is possible that flashers produce a differential effect depending on the speed differential between the slow-moving vehicle and the main flow of traffic. Thus, two other conditions tested were:

Test vehicle moving, 30 mph (48.3 kph)
Test vehicle moving, 40 mph (64.4 kph).

This variable was tested for both the slow-moving car and the slow-moving truck, with the flashers on and with the flashers off, at each of the eight test situations.

Figure 6 schematically presents most of the independent variables controlled for in the two field experiments. The conditions associated with just the stopped or just the disabled vehicle are not indicated in the figure.

| TIME | ROAD | UPGRADE | FOUR-WAY FLASHERS ON | | | | | | FOUR-WAY FLASHERS OFF | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | TRUCK | | | CAR | | | TRUCK | | | CAR | | |
| | | | Stopped | 30 mph | 40 mph | Stopped | 30 mph | 40 mph | Stopped | 30 mph | 40 mph | Stopped | 30 mph | 40 mph |
| NIGHT | FOUR-LANE | Slight | | | | | | | | | | | | |
| NIGHT | FOUR-LANE | Steep | | | | | | | | | | | | |
| NIGHT | TWO-LANE | Slight | | | | | | | | | | | | |
| NIGHT | TWO-LANE | Steep | | | | | | | | | | | | |
| DAY | FOUR-LANE | Slight | | | | | | | | | | | | |
| DAY | FOUR-LANE | Steep | | | | | | | | | | | | |
| DAY | TWO-LANE | Slight | | | | | | | | | | | | |
| DAY | TWO-LANE | Steep | | | | | | | | | | | | |

Figure 6. Major independent variables.

## Dependent Variables

Dependent variables are those that change as a result of changes in the independent variables. The questions examined in this study were: How do drivers respond to four-way flashers? What effects do the other independent variables have on the driver's response? Do these responses result in safer highway conditions?

Dependent measures were developed to permit the responses of approaching drivers to be quantified. By instrumenting a half-mile (0.8-km) or more of roadway at each test site, driver behavior can be studied at different distances relative to the test vehicle. The interaction between the subject and the test vehicle was examined at various approach distances, while the subject vehicle was overtaking and pulling away from the test vehicle.

The Traffic Evaluator System (for which documentation has been presented in previous submissions to the Federal Highway Administration) automatically collected all the data for the dependent variables.

The Traffic Evaluator System (TES) measured:

- Speed Flow Descriptors
  - Mean speed
  - Speed variance
  - Headway
  - Headgap
  - Tailway
  - Tailgap
- Speed Derivatives
  - Acceleration
  - Deceleration

- Descriptors of Passing Behavior
  - Front closure speed (relative speed)
  - Rear closure speed
  - Lateral changes within lane
  - Lane changes
- Measures of Delay
  - Following vehicles
  - Queue characteristics.

In addition to the data collected directly by TES, two additional variables were manually coded onto the TES data recording instrument. These variables included:

- Brake light applications
- Erratic maneuvers.

The general dependent variables just described are those that were used to develop specific dependent measures for the disabled vehicle study and the slow-moving vehicle study. These specific dependent measures are described in subsequent sections dealing with the disabled vehicle and slow-moving vehicle experimental results.

## Methodology

The experimental methodology involved developing procedures to simulate the presence of a disabled vehicle on the shoulder and to simulate the presence of a slow-moving vehicle in the traffic stream. Once the events were staged, the effects of the independent variables on the dependent variables could be determined. This discussion of methodology addresses the site selection and test procedures.

Site Selection. Site selection involved identifying locations to be used for testing that would eliminate or minimize the effects of extraneous variables. The following discussion describes some of the more obvious confounding variables and indicates how they were controlled.

- *Subjects seeing the test vehicle at different distances relative to the test site.* Each test site began just after a visual blockage, i.e., a hill or curve, thus minimizing the effect of those drivers who scan further down the road than others.

- *Different entry speeds of subject vehicles.* This was controlled in three ways. All sites were on roads with speed limits of at least 50 mph (80.5 kph). All the sites were sections of rural, free-flowing highways. In the moving situation, potential subject vehicles that were moving exceptionally fast or slow were not selected. In the disabled situation, a preliminary stage of data reduction was to initialize all entry speeds to 50 mph (80.5 kph).

- *Conditions that affect drivers.* Of chief concern here was the effect of the setting sun on driver performance. To avoid this problem, none of the sites faced West.

- *High accident sites.* The accident history of all the sites was checked to verify that none of the sites had more than one accident in the last three years.

- *Other site conditions that might affect subject behavior.* Some drivers change their speed or alertness when proceeding through certain locales. The sites were selected away from all the following:

Police headquarters
Schools
Construction areas
Road surface changes
Lighted portions of the highway.

- *Temporary conditions that might affect subject behavior.* The county and state maintenance departments were contacted to verify that no roadwork or mowing was to take place at the test sites during the time of the experiment.

Sites were selected to control these potentially confounding variables and to cover the range of independent variables discussed earlier. Four sites, two 2-lane and two 4-lane locations, were selected. The location of the four test sites was as follows:

Site 1: <u>Four lanes, slight upgrade</u>

Location: In Maryland; on U.S. 15, approximately 8 miles (12.9 km) north of Frederick; commencing at Stull Road and ending just before Maryland Route 806 crosses U.S. 15; facing south.

Site 2: <u>Four lanes, steep upgrade</u>

Location: In Maryland; on U.S. 340, approximately 10 miles (16.1 km) from Harpers Ferry; commencing 0.8 miles (1.3 km) after the Maryland 180, Petersville exits and ending 2 miles (3.2 km) before the exit leading into Jefferson, Maryland; facing northeast.

Site 3: <u>Two lanes, slight upgrade</u>

Location: In Maryland; on U.S. 15, approximately 14 miles (22.5 km) north of Frederick; commencing where Maryland Route 806 crosses 15 and ending just before Spahr's Quarry Road; facing south.

Site 4: Two lanes, steep upgrade

Location: In Maryland; on Maryland Route 97; approximately 10 miles (16.1 km) south of Westminster; commencing 2 miles (3.2 km) after Bartholow Road and ending just before Nicomedes Road; facing north.

Table 7 shows the traffic volume, percent grade, and estimated percentage of truck traffic at the sites.

Test Procedures. This section describes how the experimental site was instrumented to permit the collection of the dependent measures and how the disabled and slow-moving conditions were staged.

The Traffic Evaluator System (TES) was installed at each of the four test sites. The TES is an electronic system which collects computer-readable data on traffic flow. The system permitted computer reconstruction of vehicle trajectories and the interactions among all vehicles as they passed through an instrumented segment of highway. The major components of the TES included:

- An array of tapeswitches that transmitted an electrical pulse when vehicle presence was detected
- An electronic coding unit, a digital tape recorder, and an electronic clock
- A series of computer programs that reconstructed the actions of the vehicles and prepared descriptive statistics.

The tapeswitch sensors consisted of two metal strips separated by plastic spacers and enclosed in a protruding plastic jacket. When the vehicle's tire rolled onto the switch,

Table 7.

Road and Traffic Characteristics
of the Four Research Sites

| Site | Traffic* Volume | Percent** Grade | Estimated % Truck |
|---|---|---|---|
| US 15 4-lane | 14,500 | 2% | 10 - 15% |
| US 340 4-lane | 9,400 | 6% | 10% |
| US 15 2-lane | 11,800 | 2% | 10 - 15% |
| MD 97 2-lane | 5,900 | 5% | 5 - 10% |

*Maryland Department of Transportation, 1976 Average Daily Totals

**Actual Maryland Department of Transportation measurements, rounded to nearest whole percents the metal strips were pressed together to complete an electrical circuit. The switches were placed on the road by affixing double-faced tape to the underside of the switch, attaching it to the roadway, and covering the switch with a layer of wide, dark green duct tape. The switches were placed in pairs four feet (1.2 m) apart to provide the speed measures. In addition to the two parallel switches, a diagonally placed tapeswitch, used to detect lateral placement within a traffic lane, was a component of most tapeswitch "traps." Because of the switches' low profile (3/16-inch [5-mm] thick) and the color of the duct tape, drivers seldom noticed them. The traps were located 300 feet (91.5 m) apart and a total length of 2,400 feet (823.5 m) were instrumented at each site. The main difference between the test arrays for the two-lane and the four-lane highways was that only one lane of traffic was instrumented on the two-lane road, while two lanes (same direction of flow) were instrumented at the four-lane sites.

Figure 7 shows the tapeswitch array and vehicle placement for the disabled vehicle test. Figure 8 shows the tapeswitch array for the slow-moving vehicle test.

Staging the disabled vehicle and slow-moving vehicle conditions required realistic situations so that the behavior of approaching drivers could be measured reliably. Throughout the data collection effort great care was exercised to control any extraneous effects. If, for example, a hitchhiker passed through the array or if a police car parked in the array, the event was carefully recorded and the data from that time segment were not analyzed. The remaining portions of this section address how the disabled vehicle condition and the slow-moving vehicle condition were staged.

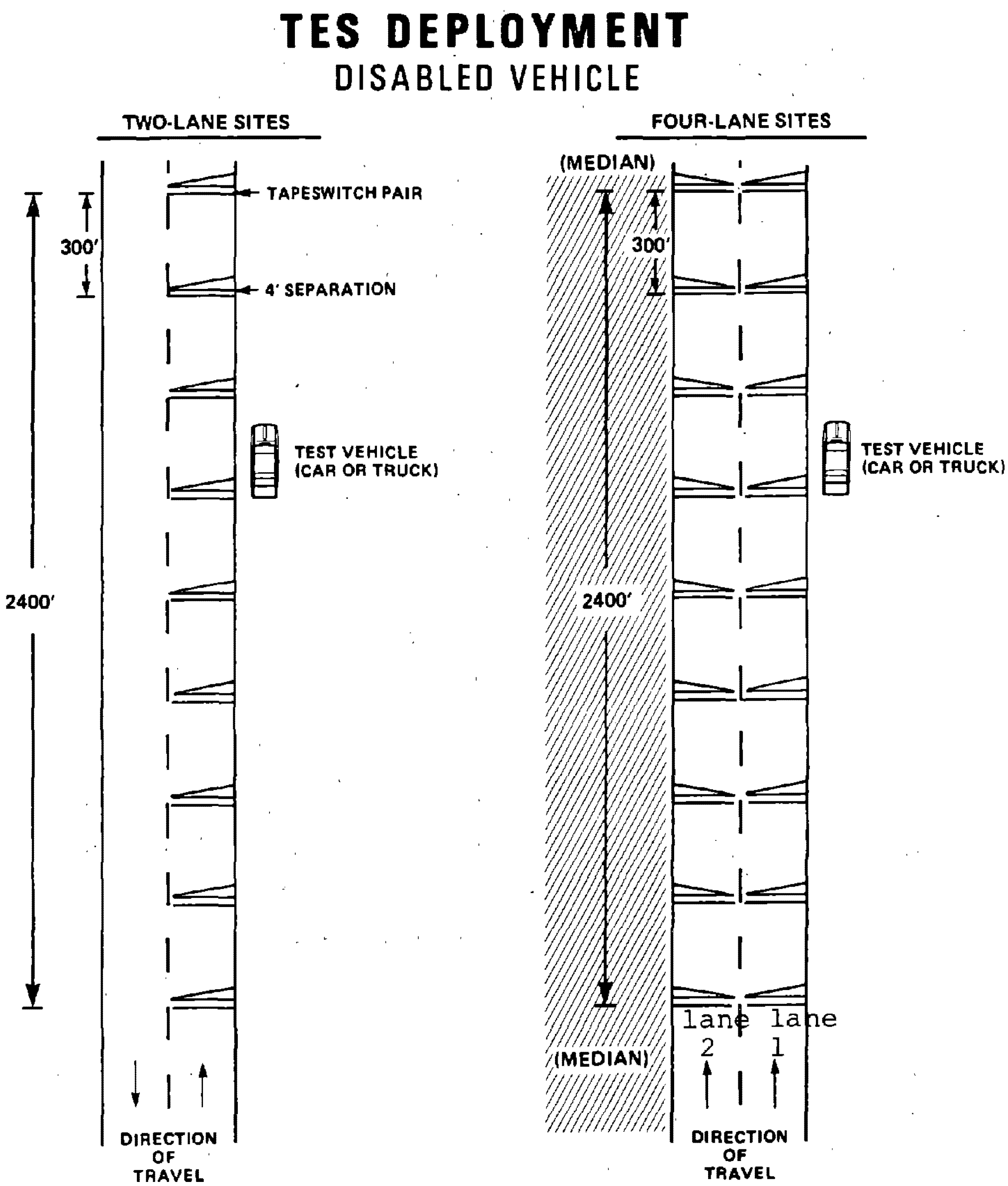



Figure 7. Tapeswitch array and vehicle placement for the disabled vehicle test.

1 foot = .3 m

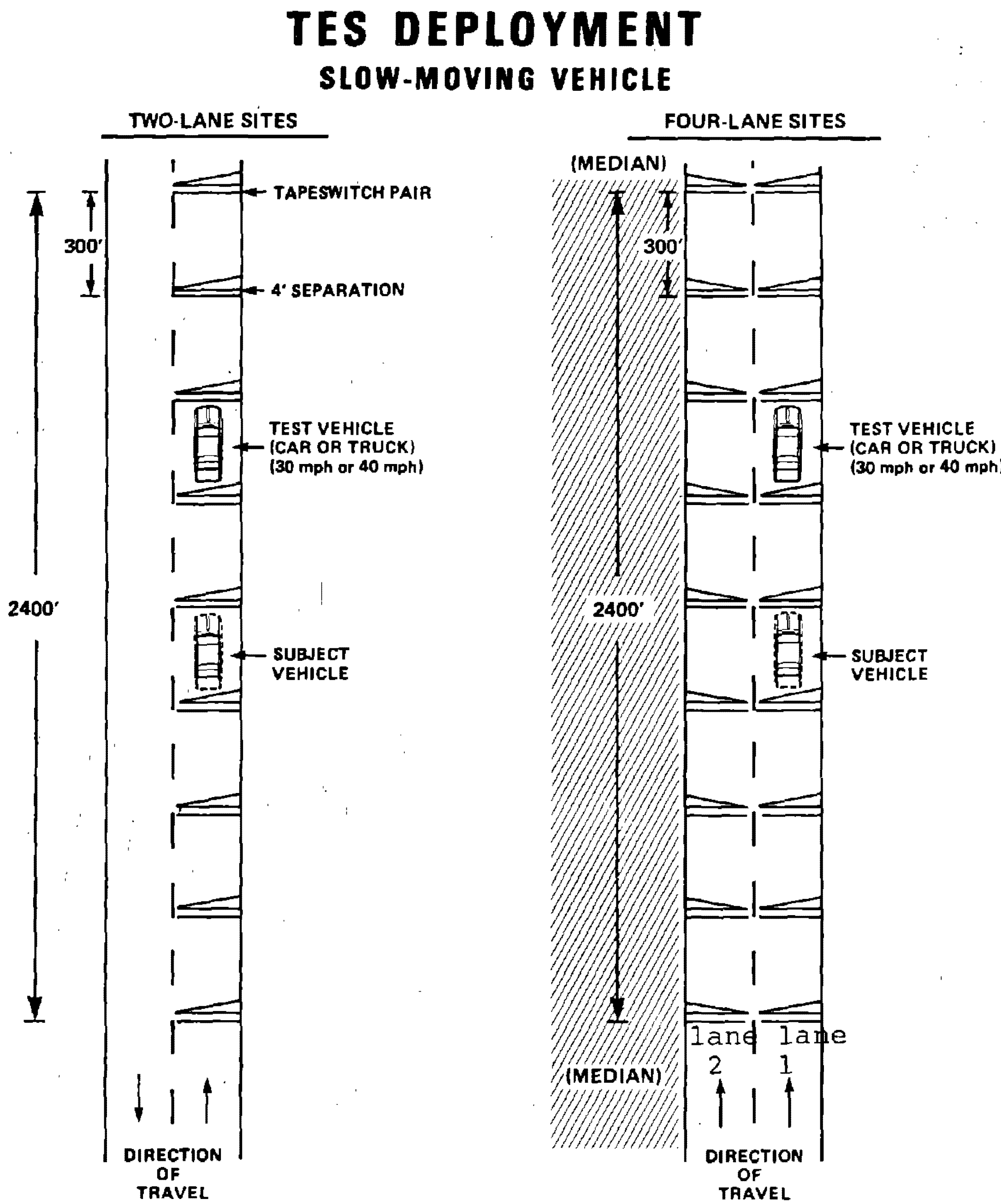



Figure 8. Tapeswitch array and vehicle placement for the slow-moving vehicle test.

1 foot = .3 m

1 mph = 1.6 kph

For the disabled vehicle condition either the car or the tractor-trailer was parked on the shoulder in the instrumented array 1-1/2 to 2 feet (0.5 to 0.6 m) from the outside pavement edge marking, and 30 feet (9 m) beyond the sixth switch pair in the array. A covert observer was stationed in the underbrush 600 to 900 feet (180 to 270 m) before the disabled vehicle. The observer coded overt driver behaviors such as brake light applications, wiggles, and erratic maneuvers. See Section II Dependent measures, (for definitions of these terms). The various disabled vehicle test conditions were tested by making changes to the basic disabled vehicle condition. The following test conditions were staged:

- Disabled Vehicle Only, No Features. The car or truck parked on the shoulder with no lights, flashers, or other features.

- Flashers On. The disabled vehicle had its flashers operating. For the disabled car, two flashers-on conditions were tested: flashers on, red; and flashers on, amber. The wiring of the car was modified so that a simple toggle switch changed the flashers from red to amber or vice-versa.

- Headlights On. The disabled car was staged with the parking lights on and the disabled truck with the running lights on. This condition is referred to as "headlights on" and was tested only at night.

- Flares. Standard 20-minute highway flares were deployed near the disabled vehicle. Two placement procedures were evaluated: standard and tapered. The placements are described in detail in Sections II and III.

- Triangles. Standard reflectorized warning triangles were deployed near the disabled vehicle. As with the flare condition, two placements were evaluated.

- Bystanders. One of the field crew, either a man or a woman, stood next to the disabled car so as to be visible to oncoming traffic. This condition was staged only for the car during daylight.

- Raised Hood or Trunk. The disabled vehicle was parked along the shoulder with either the hood up or the trunk up. This condition was staged only for the car during daylight. No bystander was visible.

No data were collected during the time that the experimental conditions were being changed.

Staging the slow-moving vehicle condition involved carefully timing the introduction of the test vehicle into the traffic stream so that the interaction between the slow-moving test vehicle and the overtaking subject vehicle would occur on the instrumented roadway section. This was accomplished by having one of the field crew, the advance spotter, stationed about a mile (1.6 km) before the experimental site. The driver of the test car (or truck) would park on the shoulder about a half mile (0.8 km) from the instrumented section. The advance spotter would identify an appropriate target vehicle, either a lone vehicle or the lead vehicle in a platoon, traveling at or near the speed limit. When the target vehicle passed a predetermined point, the advance spotter would inform the driver of the waiting test vehicle. The driver of the test vehicle would then pull out and accelerate to the appropriate test speed, either 30 mph or 40 mph (48.3 or 64.4 kph). The predetermined point was selected so that approaching subject vehicles would close on the test vehicle slightly after the midpoint of the array.

# II. DISABLED VEHICLE STUDY

## Introduction

The following subsection describes the test situations under which the various disabled vehicle conditions were examined and the dependent measures that were collected and analyzed. Subsequent subsections deal with specific hypotheses that were examined to test the effects of:

- Red four-way flashers
- Amber four-way flashers
- Headlights (parking or running lights)
- Flares, including standard and tapered placements
- Triangles, including standard and tapered placements
- Vehicle hood up
- Vehicle trunk up
- Female bystander near vehicle
- Male bystander near vehicle.

Each subsection begins with a statement of the hypotheses examined followed by a discussion of the data that were collected. The concluding statement indicates whether the hypothesis tested was accepted or rejected.

## Test Situations

Data were collected at each of the four experimental sites discussed in Section I, under both day and night conditions. Thus, a total of eight test situations were included in the study:

- Day, two-lane, steep grade
- Day, two-lane, slight grade
- Day, four-lane, steep grade
- Day, four-lane, slight grade
- Night, two-lane, steep grade
- Night, two-lane, slight grade
- Night, four-lane, steep grade
- Night, four-lane, slight grade.

In the discussion that follows, the term "conditions" is used to describe the various independent variables being evaluated. The term "situations" is used to distinguish between the various site-specific situations included in the experimental paradigm. Because of the pervasive effect the various situations tended to exert on many of the dependent variables, the results are typically presented for each of the eight situations listed.

## Dependent Measures

The following dependent measures were collected and analyzed:

- Vehicle speed, Lane 1, (See Figure 8) in 300-foot (90-m) intervals for 1,500 feet (450 m) prior to and 900 feet (270 m) after the disabled vehicle.
- Vehicle speed, Lane 2, same increments as Lane 1 vehicle speed.
- Vehicle mean speed, Lane 1. The average speed across all traps in Lane 1.
- Vehicle mean speed, Lane 2. The average speed across all traps in Lane 2.
- Acceleration, Lane 1, in 300-foot (90-m) intervals for 1,500 feet (450 m) prior to and 900 feet (270 m) after the disabled vehicle.
- Acceleration, Lane 2, same increments as Lane 1 acceleration.
- Mean acceleration, Lane 1. The average acceleration across all traps in Lane 1.
- Mean acceleration, Lane 2. The average acceleration across all traps in Lane 2.
- Lateral placement, Lane 1, the distance approaching vehicles tracked relative to the edge of the roadway, in 300-foot (90-m) intervals for 1,500 feet (450 m) prior to and 900 feet (270 m) after the disabled vehicle.
- Lateral placement, Lane 2, same increments as Lane 1 lateral placement.
- Distance to lane change (DLC) (for those vehicles that changed lanes); the distance that approaching vehicles were from the disabled vehicle when they changed from Lane 1 to Lane 2.

- Wiggles; a field coded description of erratic behavior (i.e., weaving within the lane) on the part of the approaching vehicle.* Wiggles were coded by a covert observer stationed approximately 900 feet (270 m) ahead of the disabled vehicle.
- Headway; the distance between an approaching vehicle and the vehicle directly ahead of it. This information was examined in Lane 1 only, in the same 300-foot (90-m) increments as speed, acceleration, and lateral placement.
- Ratio of lane changing (RLC); the number of vehicles that changed lanes prior to the disabled vehicle, expressed as a proportion of all vehicles passing through the array in Lane 1.

The initial entry speed (i.e., at 1,500 feet [450 m]) of each group was equalized to 50 mph (80.5 kph by adding) or subtracting the difference between the initial entry speed and 50 mph (80.5 kph) to each recorded trap speed. Equalizing the entry speeds makes the comparisons of speed profiles more meaningful.

*Brake light applications were also field coded. However, during the disabled vehicle study no brake light applications were observed.

## Red and Amber Flashers

The hypothesis tested was that amber flashers are more effective than red flashers. Data were collected across all disabled car conditions with both red and amber flashers displayed. Analyses were conducted to see if there was a consistent effect attributable to the color of the flashing light. Table 8 summarizes the speed at the disabled vehicle for the red flasher condition compared to the amber flasher condition. Differences in speed are shown. The differences were computed by subtracting the speed under the amber flasher condition from the speed under the red flasher condition. Comparisons are shown for the no-feature condition as well as the various disabled vehicle conditions (headlights, flares, triangles, hood up, trunk up, female bystander, and male bystander). Of the 40 comparisons shown, only 12 showed a significant effect (at the 0.05 level or better). Of the 12 significant effects, 7 indicate an increase in speed under the red flasher condition and 5 indicate a decrease in speed under the red flasher condition. Of the 40 comparisons, 16 showed a positive effect and 16 showed a negative effect. Eight of the speed difference computations resulted in no effect. Adding the Lane 1 speed differences across all no feature conditions produces a +0.2 mph (+0.3 kph) difference, indicating that approaching vehicles were going virtually the same speed regardless of whether red or amber flashers were displayed. The data indicates that there are no differences between the effectiveness of red and amber flashers. Because there are no differences, all subsequent comparisons of "flashers-on" data will combine the red and amber flasher conditions.

TABLE 8.

Speed Differences in Lane 1 at the Disabled Vehicle:
Red and Amber Flashers Compared

| Situations | | | No Features | Headlights | Flares | Triangles | Hood Up | Trunk Up | Male | Female |
|---|---|---|---|---|---|---|---|---|---|---|
| Day | Two-Lane | Steep | **+.1** | ● | +.2 | 0 | +.8 | **+.6** | −.4 | −.1 |
| Day | Two-Lane | Slight | 0 | ● | **+.5** | **+.9** | −.3 | 0 | 0 | −.1 |
| Day | Four-Lane | Steep | **+.2** | ● | +.2 | **+.5** | **−.5** | ● | −.2 | 0 |
| Day | Four-Lane | Slight | −.1 | ● | −.2 | **−2.0** | ● | −.3 | **+.2** | 0 |
| Night | Two-Lane | Steep | −.5 | −.9 | +.2 | **−2.2** | ● | ● | ● | ● |
| Night | Two-Lane | Slight | ● | **−.8** | ● | 0 | ● | ● | ● | ● |
| Night | Four-Lane | Steep | −.3 | +.6 | +.5 | 0 | ● | ● | ● | ● |
| Night | Four-Lane | Slight | +.8 | +.6 | +.6 | **+.6** | ● | ● | ● | ● |

Legend: Shaded differences are significant (.05 level); ● indicates no data available, differences computed by subtracting "amber" speeds from "red" speeds at this disabled vehicle.

## Flashers On Versus Flashers Off

The hypothesis tested was that displaying four-way flashers reduces the accident potential in the vicinity of the disabled vehicles. Flashers-on/flashers-off comparisons were made for the following independent variable conditions:

- Flashers on versus off: No features; car only
- Flashers on versus off: No features; truck only
- Flashers on versus off: Headlights on; car only
- Flashers on versus off: Headlights on; truck only
- Flashers on versus off: Flares; car only
- Flashers on versus off: Flares; truck only
- Flashers on versus off: Triangles; car only
- Flashers on versus off: Triangles; truck only
- Flashers on versus off: Hood up; car only
- Flashers on versus off: Trunk up; car only
- Flashers on versus off: Female bystander; car only
- Flashers on versus off: Male bystander, car only.

Table 9 summarizes the differences in the Lane 1 speed at the disabled vehicle for the flashers-on versus flashers-off comparisons. The amount and direction of the change, as well as the statistical significance, is also indicated. Flashers alone (no features condition) reduced speeds in six of the eight testing situations involving the disabled car with no features. These reductions were significant in two of the six. Neither of the two speed increases were significant. The largest speed reduction amounted to 1.2 mph (1.9 kph). A similar effect was found in the no features, truck situations. Significant reductions were found in two situations: two-lane, steep, daylight; and four-lane, slight, night. The speed differences were 1.1 mph (1.7 kph) and 2.2 mph (3.5 kph), respectively. The remaining situations produced consistent but small (less than 1 mph [1.6 kph]) reductions. The flashers-on condition also reduced Lane 1 speed when tested with the full range of independent variable conditions.

TABLE 9.

Speed Differences at Disabled Vehicle:
Flashers On vs. Flashers Off

| Light Condition | Day | | | | Night | | | |
|---|---|---|---|---|---|---|---|---|
| **Number of Lanes** | **Two Lanes** | | **Four Lanes** | | **Two Lanes** | | **Four Lanes** | |
| **Grade** | **Steep** | **Slight** | **Steep** | **Slight** | **Steep** | **Slight** | **Steep** | **Slight** |
| **Condition** | | | | | | | | |
| No features: car | −1.1 | −.5 | −1.2 | −.1 | −1.8 | +2.4 | −4.5 | +.4 |
| No features: truck | −1.1 | −.5 | +.1 | −.2 | −.3 | −.8 | ● | −2.2 |
| Headlights on: car | | | | | −3.4 | −4.7 | −3.9 | +1.7 |
| Headlights on: truck | | | | | −1.7 | −.4 | +3.3 | −.9 |
| Flares: car | +.6 | −1.7 | .0 | −.1 | +.2 | +3.4 | −1.1 | −1.4 |
| Flares: truck | +.8 | −.3 | −.8 | +.3 | −.5 | +.9 | +.3 | +.5 |
| Triangles: car | −.4 | +.8 | −2.1 | −.2 | −.4 | ● | ● | −1.0 |
| Triangles: truck | −1.1 | −.7 | −.3 | −.2 | −1.3 | +2.5 | −1.6 | −1.5 |
| Hood up: car | −1.8 | ● | −1.8 | +.2 | | | | |
| Trunk up: car | −4.7 | ● | −1.0 | −.7 | | | | |
| Female bystander: car | +1.1 | −1.1 | −1.1 | −.4 | | | | |
| Male bystander: car | −.4 | −.4 | −.6 | .6 | | | | |

Legend: Shaded values are significant (.05 Level); ● indicates no data.
Speed differences computed by subtracting flashers off speed from flashers-on speed, i.e. negative values indicate slower speed for flashers on condition.

The largest reduction noted occurred when the flashers-on, trunk-up condition was compared with the flashers-off, trunk-up condition. This reduction was 4.7 mph (7.5 kph) and was significant at the 0.001 level.

Table 10 similarly summarizes the differences in Lane 1 mean speed (over all traps) for all test conditions, comparing flashers-on to flashers-off. For the no features, car condition a significantly lower mean speed was found for five of the eight situations. The differences were relatively small, varying from 0.4 mph (2.0 kph) to 3.2 mph (5.2 kph). Similar, but smaller, differences were found in the no features, truck condition. Significant reductions of 0.7 mph (1.1 kph) and 1.5 mph (2.4 kph) were found in two of the truck test situations. Reductions were found in all but one of the remaining situations.

Both of these exhibits show that the presence of the other test conditions (i.e., flares, triangles, hood up, trunk up, and bystanders) tended to influence the effectiveness of the four-way flashers. For example, in the two-lane, steep, daylight situation, the flashers alone produced a significant 1.1 mph (1.8 kph) reduction in speed at the disabled vehicle. With flares deployed, the flashers-on versus flashers-off comparisons produced an increase in speed for the flashers-on test. On the other hand, several of the other conditions (i.e., hood up and trunk up) tended to increase the flashers-on effect at several of the sites. A detailed discussion of the various disabled vehicle conditions and their effects on flasher effectiveness is presented in the next subsection.

TABLE 10.

Differences in Mean Speed, Lane 1: Flashers On vs. Flashers Off

| Light Condition | Day | | | | Night | | | |
|---|---|---|---|---|---|---|---|---|
| Number of Lanes | Two Lanes | | Four Lanes | | Two Lanes | | Four Lanes | |
| Grade | Steep | Slight | Steep | Slight | Steep | Slight | Steep | Slight |
| **Condition** | | | | | | | | |
| No features: car | −.5 | −.4 | −.6 | −.1 | −1.5 | +2.2 | −3.2 | .0 |
| No features: truck | −.7 | −.1 | −.2 | .0 | −.2 | −.4 | ● | −1.5 |
| Headlights on: car | | | | | −1.2 | −3.6 | −2.7 | +1.0 |
| Headlights on: truck | | | | | −.7 | −.6 | +2.6 | −.5 |
| Flares: car | .0 | −.9 | +.2 | −.1 | −.8 | −.3 | −.3 | .0 |
| Flares: truck | +1.3 | −.1 | −.3 | +.3 | −.2 | +1.2 | −.1 | +.6 |
| Triangles: car | −.3 | +.5 | −.9 | −.1 | −.5 | ● | ● | −.7 |
| Triangles: truck | −.5 | −.5 | .1 | +.1 | −.8 | +.7 | −.5 | −.7 |
| Hood up: car | −2.3 | ● | −1.4 | +.6 | | | | |
| Trunk up: car | −2.8 | ● | −.8 | −.4 | | | | |
| Female bystander: car | +.2 | −.3 | −.9 | −.3 | | | | |
| Male bystander: car | −.1 | −.4 | −.5 | −.3 | | | | |

Legend: Shaded values are significant (.05 Level), ● indicates no data.
Speed differences computed by subtracting flashers off speed from flashers on speed, i.e. negative values indicate slower speed for flashers on condition.

Table 11 is the significance level summary for the flashers-on versus flashers-off comparisons for the car, no features; truck, no features; car, headlights on; and truck, headlights on conditions.

Three dependent measures were found to be most sensitive and most descriptive and are included in this and similar tables: speed at the disabled vehicle mean speed, and lateral placement. In the disabled car condition, the speed at disabled vehicle data are the same as that presented in Table 9. The Lane 1 mean speed data are supportive of the trends seen in the speed at disabled vehicle data. Although the reductions in mean speed are small, they are consistent. Six of the eight situations produced significant effects. The two-lane slight site produced the only positive mean speed. Note that there were no consistent differences in lateral placement produced by the flashers. Small positive and negative lateral placement changes are shown. There was no effect apparent in the flashers-on vs. flashers-off comparisons with the headlights on. Approaching traffic did not go slower when both headlights and flashers were displayed. This effect is especially apparent in the Lane 1 mean speed data.

The effects of flashers has been shown to be relatively consistent across the eight experimental situations. An examination of the flashers-on vs. flashers-off speed profiles for the eight situations reveals that the effect is also consistent within each situation. Table 12 shows the magnitude of the differences in speed between the flashers-on vs. flashers-off conditions at each of the nine traps in the instrumented roadway sections. Since the speed data were initialized to 50 mph (80.5 kph) at the first trap, all of the 1,500-foot (450 m) before differences are zero. After that, most of the experimental situations show a gradual increase in the speed differences up to the disabled vehicle. Only the two-lane, slight grade site under nighttime conditions deviates from the pattern. This exhibit also provides an excellent example of the need to interpret "statistical"

TABLE 11.

Significance Level Summary
Flashers On vs. Off Car, Truck,
With and Without Headlights

**Comparison:** FLASHERS ON VS. FLASHERS OFF
**Condition:** DISABLED CAR

| | | | HEADLIGHTS OFF | | | | | | HEADLIGHTS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | −1.1 | X | −.5 | X | −.1 | X | | | | | | |
| | | Slight | −.5 | | −.4 | | +.2 | | | | | | | |
| | 4 Lane | Steep | −1.2 | −.6 | −.6 | −.5 | −.1 | −.6 | | | | | | |
| | | Slight | −.1 | −2.3 | −.1 | −1.2 | −.2 | 0 | | | | | | |
| NIGHT | 2 Lane | Steep | −1.8 | X | −1.5 | X | +.2 | X | −3.4 | X | −1.2 | X | −.1 | X |
| | | Slight | +2.4 | | +2.2 | | +.6 | | −4.7 | | −3.6 | | −.2 | |
| | 4 Lane | Steep | −4.5 | +.4 | −3.2 | +2.6 | +.3 | ● | −3.9 | −3.3 | −2.7 | −3.4 | −.6 | ● |
| | | Slight | +.4 | 0 | 0 | ● | 0 | ● | +1.7 | +.7 | +1.0 | −.1 | +.1 | ● |

**Comparison:** FLASHERS ON VS. FLASHERS OFF
**Condition:** DISABLED TRUCK

| | | | HEADLIGHTS OFF | | | | | | HEADLIGHTS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | −1.1 | X | −.7 | X | +.1 | X | | | | | | |
| | | Slight | −.5 | | −.1 | | +.2 | | | | | | | |
| | 4 Lane | Steep | +.1 | +.9 | −.2 | +.9 | −.2 | −.4 | | | | | | |
| | | Slight | −.2 | −.7 | 0 | −.6 | −.3 | −.1 | | | | | | |
| NIGHT | 2 Lane | Steep | −.3 | X | −.2 | X | 0 | X | −1.7 | X | −.7 | X | −.1 | X |
| | | Slight | −.8 | | −.4 | | +.2 | | −.3 | | −.6 | | −.1 | |
| | 4 Lane | Steep | ● | | ● | ● | ● | ● | +3.3 | +.3 | +2.6 | +1.0 | +.6 | ● |
| | | Slight | −2.2 | | −1.5 | −1.8 | 0 | ● | −.9 | −.8 | −.5 | −.7 | 0 | −.3 |

Values shown are differences computed by subtracting value of first comparison variable from value of second comparison variable.

● Indicates no data available. Shaded values are significant, 0.05, or greater.

X Indicates not applicable comparison. D.V. indicates disabled vehicle
Speed Differences are shown in miles per hour (1mph = 1.61 kph)
Lateral Placement Differences are shown in feet (1 ft = 0.3 m)
No headlights - on data were collected during the day.

TABLE 12.

Speed Differences Through Array,
Flashers On vs. Flashers Off

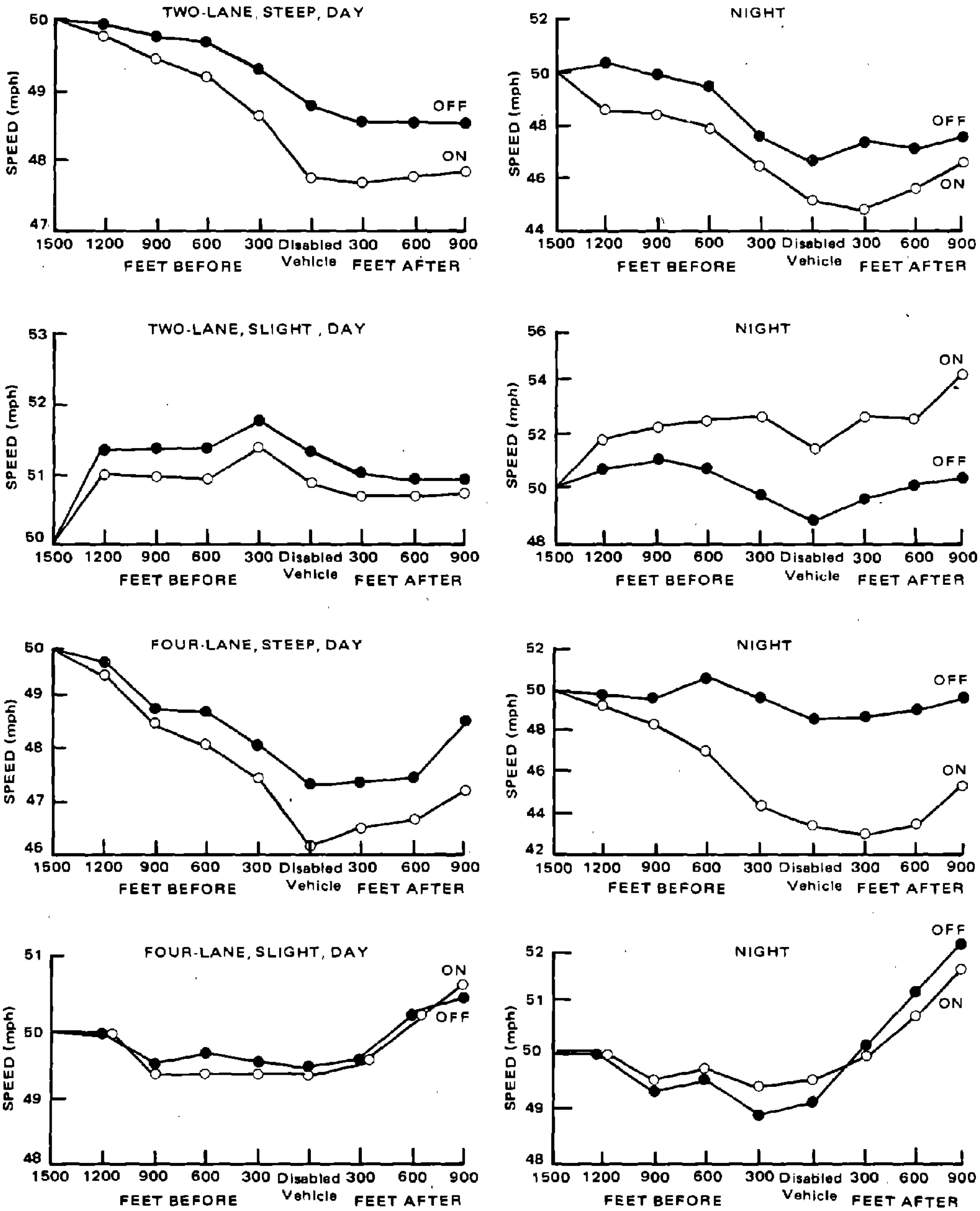
| Experimental Situation | | | | Distance From Disabled Vehicle | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Feet Before | | | | | Disabled Vehicle | Feet After | | |
| | | | | 1500 | 1200 | 900 | 600 | 300 | | 300 | 600 | 900 |
| Day | Two Lane | Steep | | 0 | −.1 | −.3 | −.5 | **−.7** | **−1.1** | **−.9** | **−.8** | −.7 |
| | | Slight | | 0 | −.3 | −.5 | −.5 | −.5 | −.5 | −.4 | −.3 | −.2 |
| | Four Lane | Steep | | 0 | −.2 | −.2 | −.6 | −.6 | **−1.2** | −1.0 | −.9 | −1.2 |
| | | Slight | | 0 | 0 | **−.1** | **−.3** | −.2 | −.1 | 0 | 0 | +.2 |
| Night | Two Lane | Steep | | 0 | −1.5 | −1.6 | −1.5 | −1.2 | −1.8 | −2.8 | −1.6 | −.9 |
| | | Slight | | 0 | +1.1 | +1.2 | **+1.9** | +2.9 | **+2.4** | **+3.2** | **+2.6** | +3.8 |
| | Four Lane | Steep | | 0 | −.4 | −1.5 | **−3.5** | −3.5 | −4.5 | −5.4 | −5.3 | −4.0 |
| | | Slight | | 0 | 0 | +.1 | +.1 | +.5 | +.4 | −.1 | −.5 | −.7 |

Values shown are mean speed for flashers on minus mean speed for flashers off, and shaded values are statistically significant (0.05 level).

significance carefully. In some situations, i.e., the four-lane, slight grade, day condition, extremely small speed differences (0.1 mph [0.16 kph]) were found to be statistically significant. In other cases, i.e., the four-lane, steep grade, day condition, identical speed differences were found to be significant at one point (600 feet [180 m] before the disabled vehicle) and not significant at another (300 feet [90 m] before). These effects are due to several factors, specifically sample size and variance. With a very large sample, it is easier for small differences to become statistically significant. Whether or not such a difference is meaningful in terms of an increase in safety is quite debatable. The other factor, variance, can have a similar effect. In one case, a difference in means may produce a significant effect. However, in another situation, the same mean difference may not be significant (even with no change in sample size) if the variability (variance) in the raw data used to compute that mean increases. The data in Table 12 clearly indicate that a consistent difference, although small in absolute terms, is apparent as far away as 1,200 feet (360 m) from the disabled vehicle.

The speed profile for each of the eight situations is graphically presented in Figures 9 and 10. These figures present the flashers-on and flashers-off plots for the disabled car and the disabled truck. Since the speed data were adjusted to equalize entry speed, all groups have a common origin of 50 mph (80.5 kph) at 1,500 feet (450 m). The plots demonstrate the information presented in Table 12: specifically, that the flasher effect starts to become apparent between 900 and 1,200 feet (270 and 360 m) from the disabled vehicle. Four-way flashers do influence the behavior of drivers of approaching vehicles. Although the absolute amount of the reduction in approach speeds is not large, it is apparent that flashers increase driver awareness and hence have the potential for improving safety in the vicinity of disabled vehicles.

Disabled Car




1 mph = 1.6 kph

1 foot = 0.3 m

Figure 9. Speed Profiles: All Situations Flashers On vs. Off, Car

Disabled Truck

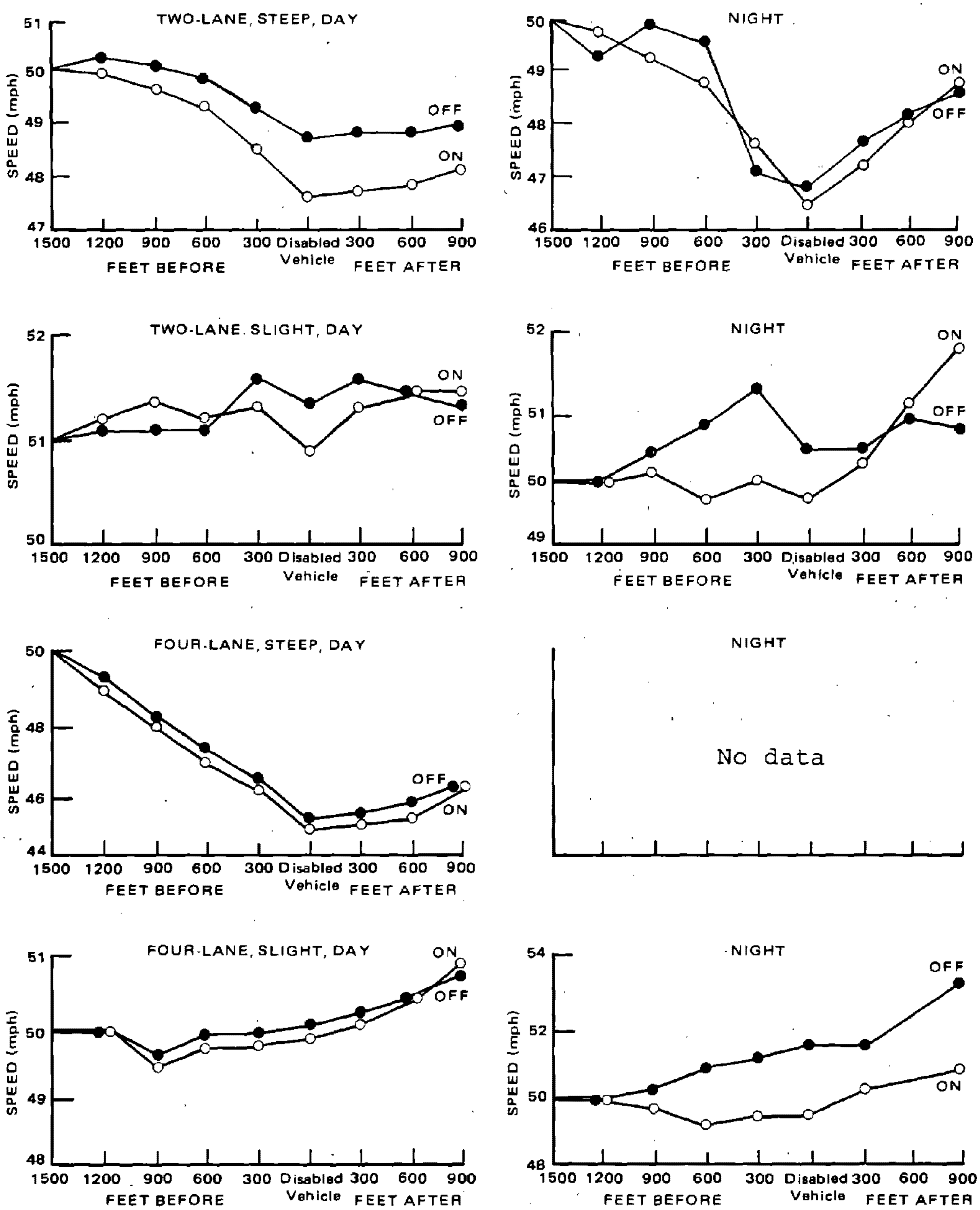



Figure 10. Speed Profiles: All Situations Flashers on vs. Flashers off.

## Disabled Vehicle Condition - Headlights On: Car and Truck

The hypothesis tested was that displaying headlights reduces the accident potential in the vicinity of disabled vehicles. The effect of having the disabled car's headlights (i.e., parking lights) on was tested under conditions with the flashers on and the flashers off. This was done at night. As shown in Table 13, the flashers-on tests produced a reduction in Lane 1 speed at the disabled vehicle of between 1.7 and 2.5 mph (2.7 and 4.0 kph). The difference was significant (0.05) in two of the four situations. In the flashers-off test, a significant increase (+4.6 mph [+7.4 kph], 0.001 level), a significant decrease (-3.3 mph [-5.3 kph], 0.01 level), and two nonsignificant decreases (-2.3 mph and -0.3 mph [-3.7 and -0.5 kph], 0.01 level) were found in Lane 1 speed. The headlights-on and flashers-on condition always produced a reduction in Lane 1 mean speed. Although the reduction was small (between 0.7 and 2.2 mph [1.1 and 3.5 kph]), it was significant in two of the four situations. No consistent changes in lateral placement were apparent.

Data were also collected on the disabled truck with the headlights (i.e., running lights) on under both the flashers-on and flashers-off condition. The presence of running lights produced a reduction in Lane 1 speed at the disabled truck in all situations tested (see Table 13). The differences were significant in two of the situations; both were with the flashers off and in the four-lane situation. The speed reduction was -3.9 mph (-6.3 kph) at the four-lane steep site and -1.6 mph (-2.6 kph) in the four-lane slight site. The Lane 1 mean speed was significantly reduced in two of the flashers-on conditions and in two of the flashers-off conditions. No significant changes in lateral placement were found. The data indicates that displaying headlights produces a slight improvement in safety in the vicinity of disabled vehicles.

TABLE 13.

Significance Level Summary
Headlights vs. No Features:
Disabled Car

**Comparison:** HEADLIGHTS VS. NO HEADLIGHTS

**Condition:** DISABLED CAR

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | | | | | | | | | | | | |
| | | Slight | | | | | | | | | | | | |
| | 4 Lane | Steep | | | | | | | | | | | | |
| | | Slight | | | | | | | | | | | | |
| NIGHT | 2 Lane | Steep | −.3 | X | −.5 | X | −.2 | X | −1.9 | X | −1.2 | X | −.5 | X |
| | | Slight | +4.6 | X | +3.6 | X | +.3 | X | −2.5 | X | −2.2 | X | −.5 | X |
| | 4 Lane | Steep | −2.3 | −4.5 | −1.2 | +5.3 | +.6 | ● | −1.7 | +.8 | −.7 | −.7 | −.3 | ● |
| | | Slight | −3.3 | 0 | −2.1 | | −.4 | ● | −2.0 | −1.4 | −1.1 | −1.3 | −.3 | −.5 |

**Comparison:** HEADLIGHTS VS. NO HEADLIGHTS

**Condition:** DISABLED TRUCK

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | | | | | | | | | | | | |
| | | Slight | | | | | | | | | | | | |
| | 4 Lane | Steep | | | | | | | | | | | | |
| | | Slight | | | | | | | | | | | | |
| NIGHT | 2 Lane | Steep | −.9 | X | −.7 | X | −.1 | X | −2.3 | X | −1.2 | X | −.2 | X |
| | | Slight | −1.6 | X | −.6 | X | +.4 | X | −1.2 | X | −.8 | X | +.1 | X |
| | 4 Lane | Steep | −3.9 | −1.5 | −2.8 | −2.1 | −.6 | ● | ● | ● | ● | ● | ● | ● |
| | | Slight | −1.6 | −1.1 | −1.1 | −.4 | +.1 | ● | −.3 | +.3 | −.1 | +.7 | +.1 | ● |

Values shown are differences computed by subtracting value of first comparison variable from value of second comparison variable.

● Indicates no data available. Shaded values are significant, 0.05, or greater.

X Indicates not applicable comparison. D.V. indicates disabled vehicle

Speed Differences are shown in miles per hour (1mph = 1.61 kph)

Lateral Placement Differences are shown in feet (1 ft = 0.3 m)

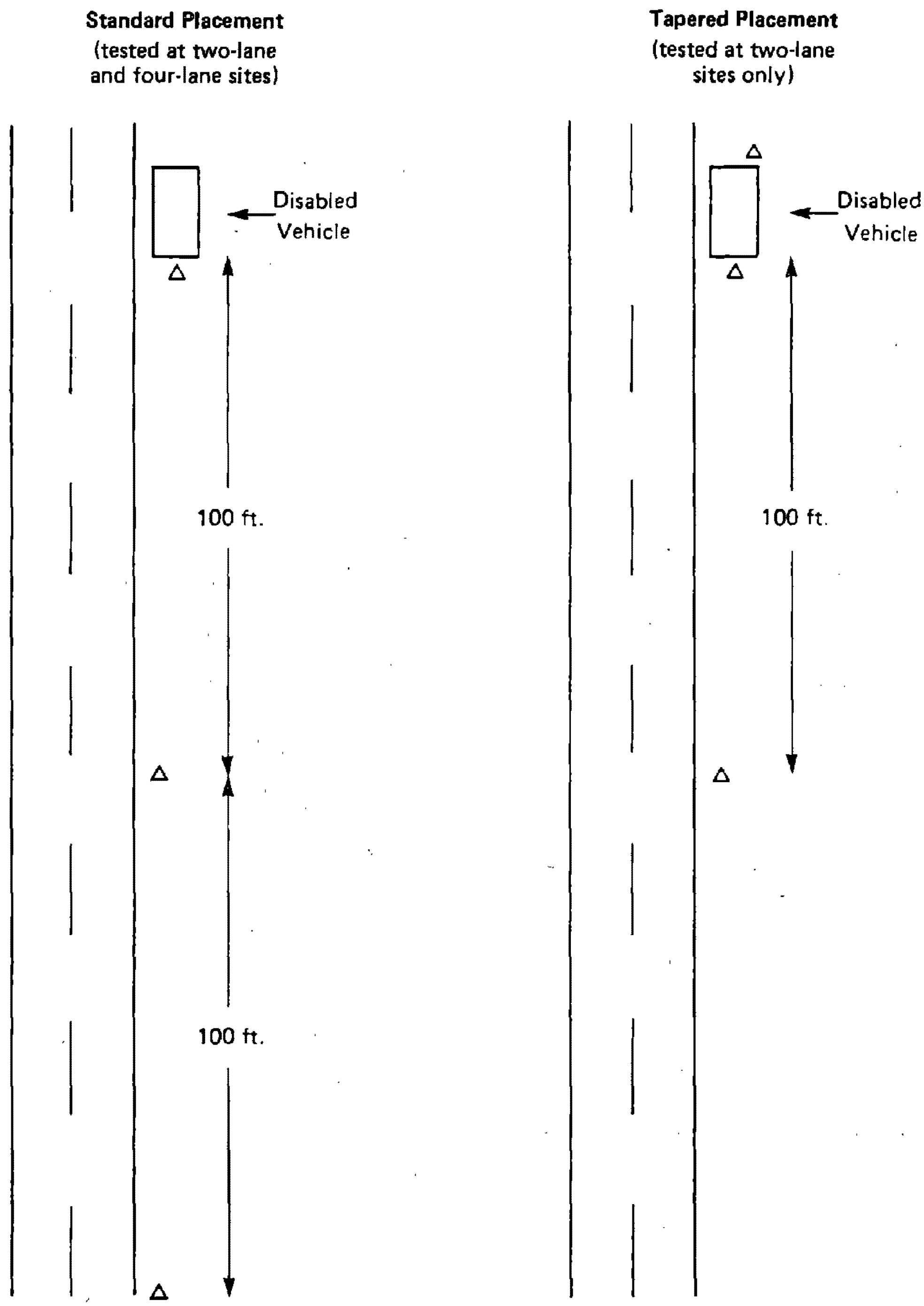
No headlights - on data were collected during the day.

## Disabled Vehicle Condition - Flares and Triangles: Car and Truck

The hypothesis tested was that displaying flares or reflective warning triangles reduces the accident potential in the vicinity of disabled vehicles. Data were collected when either highway flares or reflective warning triangles were displayed near the disabled test vehicle. Two different placement schemes were tested, as shown in Figure 11. The standard placement consisted of one device, either a flare or a triangle, centered directly behind the disabled vehicle. Additional devices were located at 100 and 200 feet (30 and 60 m) before the vehicle, 18 inches (45.7 cm) from the roadway edge. The tapered deployments used one device at the right front of the vehicle, a second device centered directly behind the vehicle, and a third 100 feet (30 m) before the second device, 18 inches (45.7 cm) from the roadway edge. The standard placement was tested at both two- and four-lane sites. The tapered placement was tested only at the two-lane sites.

In the flashers-off condition (Table 14), flares significantly reduced the Lane 1 speeds at the disabled car in all eight test situations. The reduction was significant at the 0.001 level in four cases, at the 0.01 level in three cases, and at the 0.05 level in one case. The reduction varied from 1.8 to 7.3 mph (2.9 to 11.7 kph) with a mean reduction of 4.6 mph (7.4 kph) for all eight situations. Lane 2 speeds were also reduced, although the absolute amount was somewhat less, 1.9 to 2.3 mph (3.0 to 3.7 kph).

The Significance Level Summaries, such as Table 14, show comparisons between two conditions in each of the three sections of the table. In Tables 14, and 15, for example, flares are compared against no flares in the top section, triangles against no triangles in the middle section, and flares with triangles in the bottom section. The left-most portion of each section contains data for the flashers-off condition. The right-most portion contains the flashers-on data.




*100 ft. = 31 meters.

Figure 11. Warning device deployment placements.

TABLE 14.

Significance Level Summary
Flares and Triangles: Car

**Comparison:** FLARES VS. NO FLARES
**Condition:** DISABLED CAR

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | –4.1 | X | –1.5 | X | 0 | X | –2.4 | X | –1.0 | X | +.3 | X |
| | | Slight | –2.1 | X | –.9 | X | +.5 | X | –3.3 | X | –1.4 | X | –.2 | X |
| | 4 Lane | Steep | –4.1 | –1.9 | –2.2 | –1.4 | –.4 | +.4 | –2.9 | –.8 | –1.4 | –.9 | 0 | –.1 |
| | | Slight | –1.8 | –2.3 | –.7 | –1.2 | –.5 | 0 | –1.8 | +.4 | –.7 | +.2 | –.3 | +.1 |
| NIGHT | 2 Lane | Steep | –7.3 | X | –3.5 | X | +.1 | X | –5.3 | X | –2.8 | X | +.3 | X |
| | | Slight | –7.3 | X | –1.9 | X | +.7 | X | –6.3 | X | –4.4 | X | +.3 | X |
| | 4 Lane | Steep | –6.6 | | –3.0 | +2.3 | +.5 | ● | –3.2 | –.5 | –.1 | +.4 | –.1 | +.1 |
| | | Slight | –3.2 | | –2.1 | ● | –.7 | ● | –5.0 | –3.6 | –2.1 | –2.6 | –.3 | +.2 |

**Comparison:** TRIANGLES VS. NO FLARES
**Condition:** DISABLED CAR

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | –2.2 | X | –1.0 | X | +.3 | X | –1.5 | X | –.8 | X | +.2 | X |
| | | Slight | –1.3 | X | –.7 | X | +.2 | X | 0 | X | +.2 | X | 0 | X |
| | 4 Lane | Steep | –.7 | –2.6 | –.4 | –1.9 | +.2 | .0 | –1.6 | –1.3 | –.7 | –.9 | –.2 | –.4 |
| | | Slight | –.6 | –.7 | –.5 | –.6 | –.4 | –.6 | –.7 | +1.2 | –.5 | +.8 | +.2 | –.4 |
| NIGHT | 2 Lane | Steep | –2.3 | X | –1.3 | X | 0 | X | –.9 | X | –.3 | X | –.4 | X |
| | | Slight | ● | X | ● | X | ● | X | –3.1 | X | –2.2 | X | –.2 | X |
| | 4 Lane | Steep | ● | ● | ● | ● | ● | ● | +2.0 | +2.9 | +1.8 | +1.8 | –.2 | 0 |
| | | Slight | –.9 | ● | –.7 | ● | –.1 | ● | –2.3 | –1.6 | –1.4 | –1.0 | +.1 | +.4 |

**Comparison:** FLARES VS. TRIANGLES
**Condition:** DISABLED CAR

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | –1.9 | X | –.5 | X | –.3 | X | –.9 | X | –.2 | X | –.1 | X |
| | | Slight | –.8 | X | –.2 | X | +.3 | X | –3.3 | X | –1.6 | X | –.2 | X |
| | 4 Lane | Steep | –3.4 | +.7 | –1.8 | +.5 | –.6 | ● | –1.3 | +.5 | –.7 | 0 | –.2 | +.3 |
| | | Slight | –1.2 | –1.6 | –.2 | –.8 | –.1 | +.6 | –1.1 | –.8 | –.2 | –.6 | –.1 | +.6 |
| NIGHT | 2 Lane | Steep | –5.0 | X | –2.2 | X | +.1 | X | –4.4 | X | –2.6 | X | +.7 | X |
| | | Slight | ● | X | ● | X | ● | X | –3.2 | X | –2.2 | X | +.5 | X |
| | 4 Lane | Steep | ● | ● | ● | ● | ● | | –5.2 | –3.4 | –1.9 | –1.4 | +.1 | +.1 |
| | | Slight | –2.3 | –6.7 | –1.4 | –3.1 | –.6 | | –2.7 | –2.0 | –.7 | –1.6 | –.4 | –.2 |

● Indicates no data available. Shaded values are significant, 0.05, or greater.

X Indicates not applicable comparison. D.V. indicates disabled vehicle
Speed Differences are shown in miles per hour (1mph = 1.61 kph)
Lateral Placement Differences are shown in feet (1 ft = 0.3 m)
Data on standard flare and standard triangle placements are shown.

# TABLE 15.

## Significance Level Summary
## Flares and Triangles: Truck

**Comparison:** FLARES VS. NO FLARES
**Condition:** DISABLED TRUCK

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | -2.0 | X | -1.9 | X | -.2 | X | -.1 | X | +.1 | X | +.2 | X |
| | | Slight | -1.1 | X | -.4 | X | +.2 | X | -.9 | X | -.4 | X | +.1 | X |
| | 4 Lane | Steep | -.1 | -.1 | -.1 | -.2 | -.4 | +.1 | -1.0 | -.9 | -.2 | -.9 | +.4 | -.1 |
| | | Slight | -.8 | -.6 | -.4 | -.3 | -.2 | +.1 | -.3 | -.3 | -.1 | +.1 | 0 | -.1 |
| NIGHT | 2 Lane | Steep | -4.8 | X | -2.8 | X | +.3 | X | -5.0 | X | -2.8 | X | +.4 | X |
| | | Slight | -3.8 | X | -2.6 | X | -.6 | X | -2.1 | X | -1.0 | X | +.1 | X |
| | 4 Lane | Steep | -4.1 | -4.1 | -1.9 | -1.9 | -.3 | ● | ● | ● | ● | ● | ● | ● |
| | | Slight | -4.5 | -2.6 | -2.3 | -1.1 | +.6 | ● | -1.8 | +.1 | -.2 | +.4 | +.1 | ● |

**Comparison:** TRIANGLES VS. NO
**Condition:** DISABLED TRUCK

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | -.2 | X | -.2 | X | +.1 | X | -.2 | X | 0 | X | +.2 | X |
| | | Slight | -.1 | X | -.1 | X | +.2 | X | -.3 | X | -.6 | X | -.1 | X |
| | 4 Lane | Steep | +.4 | +2.2 | +.1 | +1.9 | -.2 | -.1 | 0 | +.4 | +.2 | +.2 | +.2 | +.5 |
| | | Slight | -.3 | -.2 | -.1 | -.3 | -.1 | -.1 | -.3 | +.2 | 0 | +.3 | +.2 | +.2 |
| NIGHT | 2 Lane | Steep | -1.2 | X | -.8 | X | 0 | X | -2.2 | X | -1.4 | X | -.1 | X |
| | | Slight | -2.3 | X | -1.4 | X | +.7 | X | +1.0 | X | +.7 | X | +.6 | X |
| | 4 Lane | Steep | +.4 | -2.5 | .0 | -1.4 | -.8 | ● | ● | ● | ● | ● | ● | |
| | | Slight | -1.6 | -3.0 | -1.0 | -.7 | 0 | ● | -.9 | +1.7 | -.2 | +2.2 | -.1 | |

**Comparison:** FLARES VS. TRIANGLES
**Condition:** DISABLED TRUCK

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | -1.8 | X | -1.7 | X | -.3 | X | +.1 | X | +.1 | X | 0 | X |
| | | Slight | -1.0 | X | -.3 | X | 0 | X | -.6 | X | +.1 | X | +.2 | X |
| | 4 Lane | Steep | -.5 | -2.3 | -.2 | -2.1 | -.2 | +.2 | -1.0 | -1.3 | -.4 | -1.1 | +.2 | -.6 |
| | | Slight | -.5 | -.4 | -.3 | 0 | -.1 | +.2 | 0 | -.5 | -.1 | -.2 | +.2 | -.3 |
| NIGHT | 2 Lane | Steep | -3.6 | X | -2.0 | X | +.3 | X | -2.8 | X | -1.4 | X | +.5 | X |
| | | Slight | -1.5 | X | -1.2 | X | -1.3 | X | -3.1 | X | -1.7 | X | -.7 | X |
| | 4 Lane | Steep | -4.5 | -1.6 | -1.9 | -.5 | +.5 | ● | -2.6 | -.7 | -1.5 | +.5 | +.3 | ● |
| | | Slight | -2.9 | +.4 | -1.3 | -.4 | +.1 | +.5 | -.9 | -1.6 | 0 | -1.8 | +.2 | -.5 |

● Indicates no data available. Shaded values are significant, 0.05, or greater.

X Indicates not applicable comparison. D.V. indicates disabled vehicle
Speed Differences are shown in miles per hour (1mph = 1.61 kph)
Lateral Placement Differences are shown in feet (1 ft = 0.3 m)
Data on standard flare and standard triangle placements are shown.

For the disabled truck condition, the deployment of flares or reflectorized emergency triangles also produced a consistent reduction in speed at the disabled vehicle and in the Lane 1 mean speed (Table 15). With the flashers off, flares produced a significant reduction in five of the eight test situations. The speed reduction was higher at night ($\bar{x}$ = 4.3 mph [6.9 kph]) than during the day ($\bar{x}$ = 1.0 mph [1.6 kph]). Significant reductions in mean speed were found in all of the eight test situations. With the flashers on, the effect was similar but significant in only three of the seven situations for which data were available. With the flashers on, the speed reduction was somewhat less: day $\bar{x}$ = 0.6 mph (1.0 kph), night $\bar{x}$ = 3.0 mph (4.8 kph). The warning triangles produced a significant reduction in speed at the disabled truck in only one of the eight flashers-off situations and in none of the flashers-on situations. In the flares versus triangles comparisons, with the flashers off, flares produced a greater speed reduction in every Lane 1 situation. This difference was significant in three of the eight situations. When the flashers were on, the flares produced a greater reduction than triangles in six of the eight situations. These differences were significant in two situations. The above findings were similar in terms of mean speeds. No consistent differences were found in lateral placement.

Six comparisons were made of the tapered flare and tapered triangle placements:

- Flares versus tapered flares: Flashers on
- Flares versus tapered flares: Flashers off
- Triangles versus tapered triangles: Flashers on
- Triangles versus tapered triangles: Flashers off
- Tapered flares versus tapered triangles: Flashers on
- Tapered flares versus tapered triangles: Flashers off

These comparisons were made for the disabled car and the disabled truck under both day and night conditions. There were no consistent differences between the flared and standard placements in terms of speed profiles through array (Lane 1 or Lane 2), mean speeds (Lane 1 or Lane 2), acceleration rates (Lane 1 or Lane 2), distance to lane change, headway, or ratio of lane changing. Lateral placement, in the flashers-on condition, did show a consistent, and frequently statistically significant, increase when the standard placement was compared to the tapered placement. This was true for the disabled car condition only; no significant lateral placement changes were observed at the disabled truck. The lateral placement change did not appear directly at the disabled vehicle; the increases tended to occur either 300 feet (90 m) prior to or 300 feet (90 m) after the disabled vehicle. Approaching traffic tended to move over between 0.4 and 0.7 feet (0.1 and 0.2 m) more when the standard placement was used. The effect was somewhat greater for the flashers-on condition as opposed to the flashers-off condition. Tables 16 and 17 present lateral placement profiles for the regular and tapered flares and triangles for the flashers-off and flashers-on conditions, respectively.

The data indicate a very definite improvement in safety attributable to the presence of flares at a disabled vehicle. Reflective warning triangles also improve safety in the vicinity of disabled vehicles, although the effect is not as consistent and not as large as the effect attributable to the flares.

TABLE 16. Lateral Placement Profile: Flares, Tapered Flares, Triangles, Tapered Triangles: Flashers On

| KEY | EXPERIMENTAL CONDITION | 1500 FT. | | 1200 FT. | | 900 FT. | | 600 FT. | | 300 FT. | | D.V. | | 300 FT. | | 600 FT. | | 900 FT. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S |
| 1 | No Features (Flashers on) | 2.8 | 1.0 | 2.8 | 1.0 | 2.7 | 1.0 | 2.4 | 1.0 | 3.1 | 1.0 | 3.7 | .8 | 3.1 | 1.0 | 2.8 | 1.0 | 2.7 | .9 |
| 2 | Flares | 2.9 | .9 | 3.3 | .9 | 2.7 | 1.0 | 2.6 | .9 | 3.5 | .8 | 4.0 | .7 | 3.4 | .9 | 3.2 | .9 | 3.0 | .9 |
| | Flares vs no features (significant) | | | +.001 | | | | +.05 | | +.001 | | +.01 | | +.001 | | +.001 | | +.001 | |
| 3 | Tapered Flares | 2.8 | .9 | 3.0 | .9 | 2.7 | .9 | 2.5 | .9 | 3.4 | 1.0 | 3.7 | .8 | 3.0 | 1.0 | 3.0 | 1.0 | 2.7 | .9 |
| | Flares vs Tapered Flares (signif.) | | | +.05 | | | | | | | | +.05 | | +.01 | | | | +.05 | |
| 4 | Triangles | 3.0 | .9 | 3.1 | 1.0 | 2.9 | 1.0 | 2.5 | 1.0 | 3.4 | .9 | 3.9 | .8 | 3.4 | .9 | 3.0 | 1.1 | 3.0 | 1.0 |
| | Triangles vs no Features (signif) | | | +.05 | | | | | | +.05 | | | | +.01 | | +.05 | | +.01 | |
| 5 | Tapered Triangles | 2.9 | .9 | 2.9 | .9 | 2.7 | 1.0 | 2.5 | 1.0 | 3.3 | 1.0 | 3.7 | .9 | 2.9 | 1.1 | 2.9 | .9 | 2.8 | 1.0 |
| | Triangles vs Tapered Triangles | | | | | | | | | | | | | +.001 | | | | | |

Flares vs Triangles: No Significant Differences
Tapered Flares vs Tapered Triangles: No Significant Differences

**INDEPENDENT VARIABLES**

| | |
|---|---|
| √ | CAR |
| | TRUCK |
| √ | TWO-LANE |
| | FOUR-LANE |
| √ | STEEP GRADE |
| | SLIGHT GRADE |
| √ | DAYLIGHT |
| | NIGHT |

1 ft = .3m

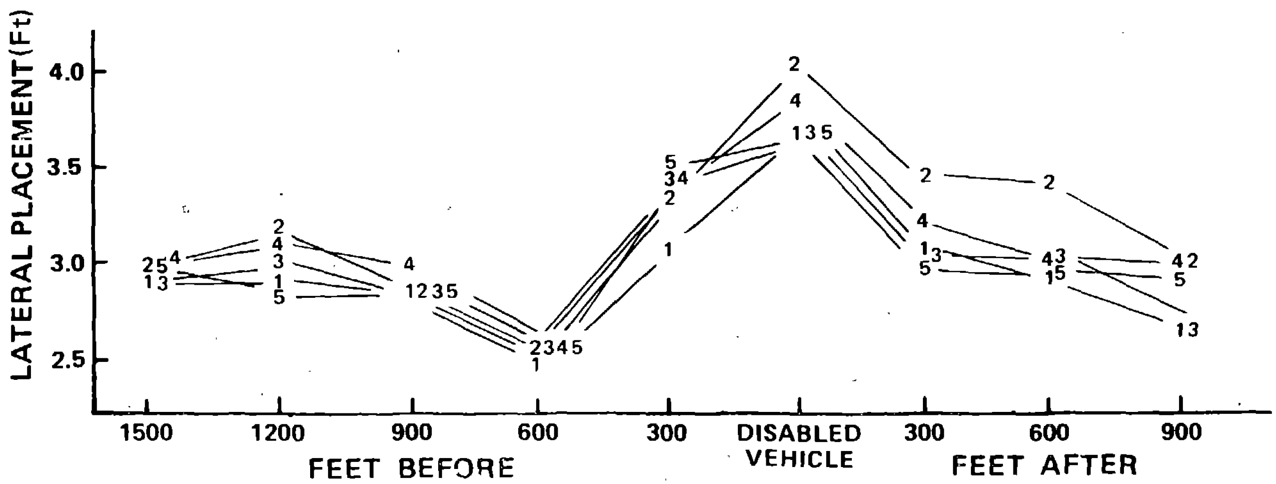


TABLE 17: Lateral Placement Profile: Flares, Tapered Flares, Triangles, Tapered Triangles: Flashers Off.

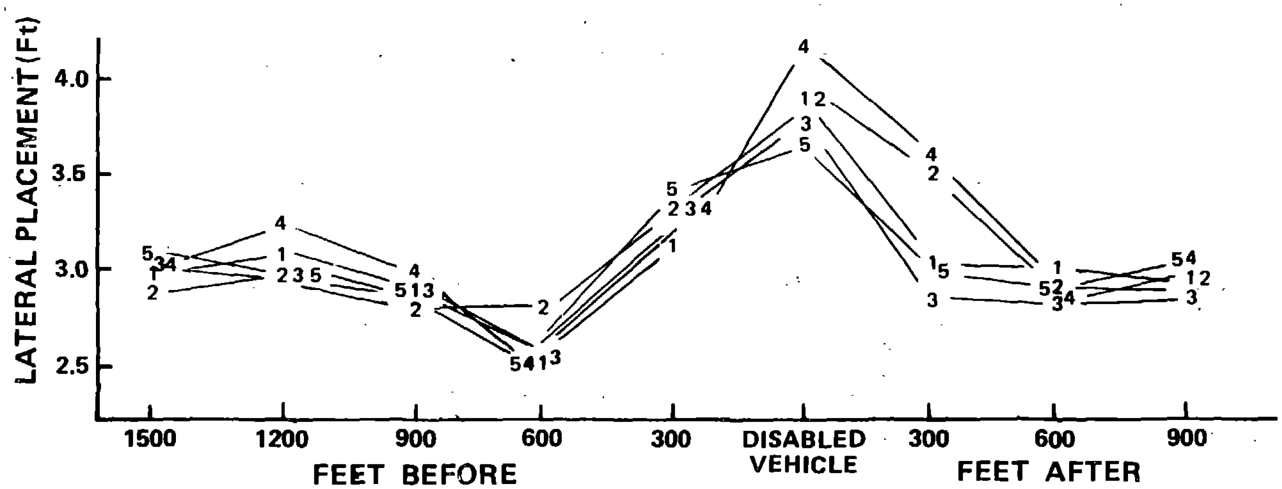
| KEY | EXPERIMENTAL CONDITION | 1500 FT. | | 1200 FT. | | 900 FT. | | 600 FT. | | 300 FT. | | D.V. | | 300 FT. | | 600 FT. | | 900 FT. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S |
| 1 | No Features (flashers off) | 2.9 | 1.0 | 3.1 | .9 | 2.8 | 1.0 | 2.5 | 1.0 | 3.2 | 1.0 | 3.8 | .7 | 3.1 | 1.0 | 3.0 | 1.0 | 2.9 | 1.0 |
| 2 | Flares | 2.8 | 1.1 | 2.9 | 1.0 | 2.7 | 1.0 | 2.7 | 1.1 | 3.3 | .9 | 3.8 | .6 | 3.5 | 1.1 | 3.1 | 1.1 | 2.9 | 1.0 |
| | Flares vs no features (significant) | | | | | | | | | | | | | +.05 | | | | | |
| 3 | Tapered Flares | 3.0 | 1.1 | 2.9 | 1.0 | 2.8 | 1.0 | 2.5 | 1.0 | 3.3 | 1.0 | 3.6 | .8 | 2.8 | 1.1 | 2.8 | .9 | 2.9 | 1.0 |
| | Flares vs Tapered Flares (signif.) | | | | | | | | | | | | | +.001 | | | | | |
| 4 | Triangles | 3.0 | 1.0 | 3.3 | 1.0 | 2.9 | 1.1 | 2.5 | 1.1 | 3.3 | .9 | 4.1 | .6 | 3.4 | 1.0 | 2.7 | 1.1 | 3.0 | 1.1 |
| | Triangles vs no Features (signif) | | | | | | | | | | | +.01 | | | | | | | |
| 5 | Tapered Triangles | 3.1 | 1.0 | 2.9 | 1.0 | 2.7 | .9 | 2.5 | .9 | 3.4 | 1.0 | 3.7 | .7 | 3.0 | 1.0 | 2.9 | .9 | 3.0 | 1.1 |
| | Triangles vs Tapered Triangles (signif.) | | | +.05 | | | | | | | | +.01 | | | | | | | |

Flares vs Triangles: no Significant Differences
Tapered Flares vs Tapered Triangles: no Significant Differences

**INDEPENDENT VARIABLES**

| | |
|---|---|
| √ | CAR |
| | TRUCK |
| √ | TWO-LANE |
| | FOUR-LANE |
| √ | STEEP GRADE |
| | SLIGHT GRADE |
| √ | DAYLIGHT |
| | NIGHT |

1ft = .3m



## Disabled Vehicle Condition - Bystanders: Car Only

The hypothesis tested was that the presence of a bystander reduces the accident potential in the vicinity of the disabled vehicle. Data were collected on approaching vehicles when either a female or a male bystander were standing at the rear of the disabled car so as to be visible to the approaching traffic. Data were collected under daylight conditions only. With the flashers off, the female bystander produced a significant reduction in Lane 1 speed at the disabled vehicle in three of the four test situations (Table 18). Lane 1 mean speed was significantly reduced in two of the four test situations. The male produced a similar effect. Lane 1 speed at the disabled vehicle was significantly reduced in three of the four situations. The Lane 1 mean speed was reduced at the 0.001 level in two of the four situations. The mean reduction of Lane 1 speed at the disabled vehicle was 2.0 mph (3.2 kph) for the female and 1.8 mph (2.9 kph) for the male. The speed at disabled vehicle differences between male and female were only significant (at the 0.05 level) with the flashers on. There was an increase in the manually coded "wiggle" behavior in two of the four female bystander situations. Wiggles were significantly increased (0.001) in one male situation and significantly decreased (0.001) in one other male situation.

An additive effect was not found when the four-way flashers were displayed in the female and male bystander conditions. Approaching traffic slowed slightly more when the flashers were not displayed and a bystander was present that it did for either the flashers alone or the bystanders next to a vehicle with the flashers displayed. As in the flashers-off condition, the female bystander was slightly more effective than the male. This difference was only approximately 1 mph (1.6 kph). The largest daytime speed reduction for all test conditions was found in the flashers-off, female bystander condition (-4.7 mph [-7.6 kph]).

TABLE 18.

Significance Level Summary:
Female and Male Bystanders, Car

**Comparison:** FEMALE BYSTANDER VS. NO BYSTANDER

**Condition:** DISABLED CAR

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | −4.7 | X | −1.7 | X | +.1 | X | −2.5 | X | −1.0 | X | +.3 | X |
| | | Slight | −1.4 | X | −.7 | X | +.3 | X | −2.0 | X | −.6 | X | +.1 | X |
| | 4 Lane | Steep | −1.1 | ● | −.3 | −.8 | 0 | 0 | −1.2 | ● | −.6 | −.7 | 0 | −.2 |
| | | Slight | −.6 | −.8 | −.2 | −.5 | −.1 | 0 | −.9 | +1.2 | −.4 | +.6 | 0 | −.2 |
| NIGHT | 2 Lane | Steep | | X | | X | | X | | X | | X | | X |
| | | Slight | | X | | X | | X | | X | | X | | X |
| | 4 Lane | Steep | | | | | | | | | | | | |
| | | Slight | | | | | | | | | | | | |

**Comparison:** MALE BYSTANDER VS. NO BYSTANDER

**Condition:** DISABLED CAR

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | −3.1 | X | −1.5 | X | −.1 | X | −2.4 | X | −1.1 | X | +.2 | X |
| | | Slight | −1.1 | X | −.2 | X | +.3 | X | −1.0 | X | −.2 | X | +.1 | X |
| | 4 Lane | Steep | −2.8 | ● | −1.2 | 0 | +.1 | +.2 | −2.2 | −2.7 | −1.1 | −1.8 | 0 | −.5 |
| | | Slight | −.1 | −.9 | 0 | −.7 | −.2 | −.1 | −.6 | +1.7 | −.2 | +.9 | 0 | +.1 |
| NIGHT | 2 Lane | Steep | | X | | X | | X | | X | | X | | X |
| | | Slight | | X | | X | | X | | X | | X | | X |
| | 4 Lane | Steep | | | | | | | | | | | | |
| | | Slight | | | | | | | | | | | | |

**Comparison:** FEMALE BYSTANDER VS. MALE BYSTANDER

**Condition:** DISABLED CAR

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | −1.6 | X | −.2 | X | +.2 | X | −.1 | X | +.1 | X | +.1 | X |
| | | Slight | −.3 | X | −.5 | X | 0 | X | −1.0 | X | −.4 | X | 0 | X |
| | 4 Lane | Steep | +1.7 | | +.9 | −.8 | −.1 | −.2 | +1.0 | ● | +.5 | +1.1 | 0 | +.3 |
| | | Slight | −.5 | +.1 | −.2 | +.2 | +.1 | +.1 | −.3 | −.5 | −.2 | −.2 | 0 | −.3 |
| NIGHT | 2 Lane | Steep | | X | | X | | X | | X | | X | | X |
| | | Slight | | X | | X | | X | | X | | X | | X |
| | 4 Lane | Steep | | | | | | | | | | | | |
| | | Slight | | | | | | | | | | | | |

No night data were collected on the bystander conditions.

● Indicates no data available. Shaded values are significant, 0.05, or greater.

X Indicates not applicable comparison. D.V. indicates disabled vehicle
Speed Differences are shown in miles per hour (1mph = 1.61 kph)
Lateral Placement Differences are shown in feet (1 ft = 0.3 m)

Since the bystander condition is not plotted in the speed profiles in Figure 9 (see page 65), speed profiles for one of the sites, showing the bystander effect, are presented in Tables 19 and 20. The first profile shows the flashers-off data; the second profile shows the flashers-on data. This is the two-lane, steep grade site which showed some of the largest speed reductions. Notice that the profiles begin to show a speed change at 600 feet (180 m) before the disabled vehicle for both the flashers-on and flashers-off conditions. The data indicate that drivers tend to approach more cautiously when a bystander is visible near a disabled vehicle.

TABLE 19: Speed Profile: Female and Male Bystanders: Flashers Off: Car

| KEY | EXPERIMENTAL CONDITION | 1200 FT. | | 900 FT. | | 600 FT. | | 300 FT. | | D.V. | | 300 FT. | | 600 FT. | | 900 FT. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S |
| 1 | Female Bystander: Flashers Off | 49.8 | 1.0 | 49.2 | 2.0 | 48.2 | 2.8 | 46.6 | 4.0 | 44.1 | 8.1 | 45.8 | 3.9 | 46.4 | 3.9 | 47.1 | 3.7 |
| 2 | Male Bystander: Flashers Off | 49.7 | 1.7 | 49.1 | 2.8 | 48.4 | 3.4 | 47.0 | 3.9 | 45.7 | 5.6 | 46.1 | 4.3 | 46.3 | 4.9 | 47.1 | 4.7 |
| 3 | No. Features: Flashers Off | 49.9 | 1.4 | 49.8 | 2.2 | 49.7 | 2.6 | 49.3 | 2.8 | 48.8 | 2.9 | 48.5 | 3.2 | 48.5 | 3.2 | 48.5 | 3.2 |
| 4 | No. Features: Flashers On | 49.8 | 1.5 | 49.5 | 2.5 | 49.2 | 3.2 | 48.6 | 3.7 | 47.7 | 4.1 | 47.6 | 4.0 | 47.7 | 4.2 | 47.8 | 4.5 |
| | Female vs. No. Features, Flashers Off: Significance | | | | | –.001 | | –.001 | | –.001 | | –.001 | | –.001 | | –.01 | |
| | Male vs. No. Features, Flashers Off: Significance | | | –.05 | | –.01 | | –.001 | | –.001 | | –.001 | | –.001 | | –.01 | |
| | Female vs. Male, Flashers Off: Significance | | | | | | | | | | | | | | | | |

**INDEPENDENT VARIABLES**

| | |
|---|---|
| √ | CAR |
| | TRUCK |
| √ | TWO-LANE |
| | FOUR-LANE |
| √ | STEEP GRADE |
| | SLIGHT GRADE |
| √ | DAYLIGHT |
| | NIGHT |

1mph = 1.6kph
1ft = .3m

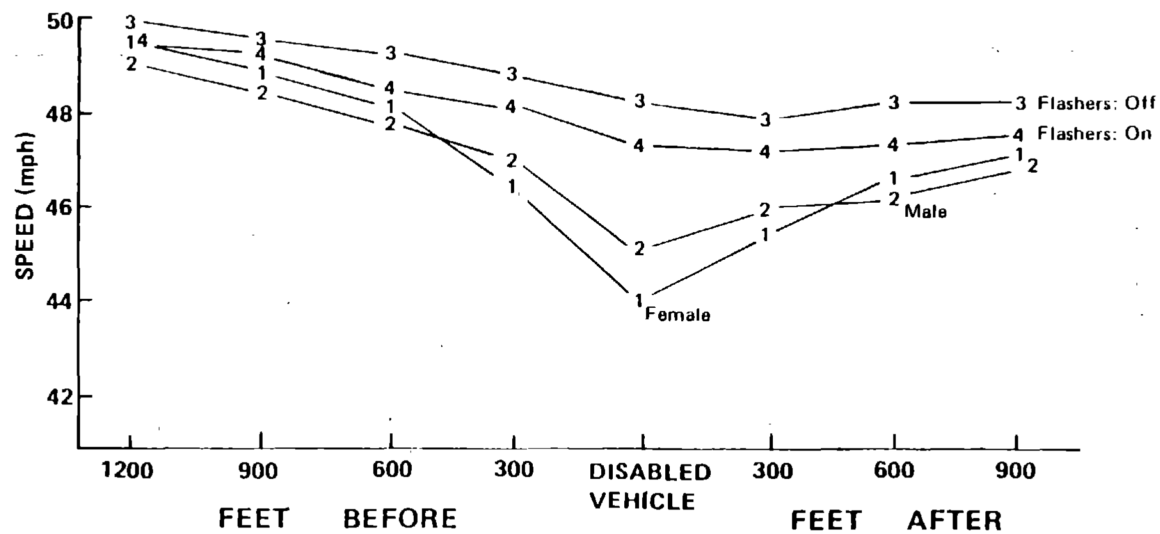


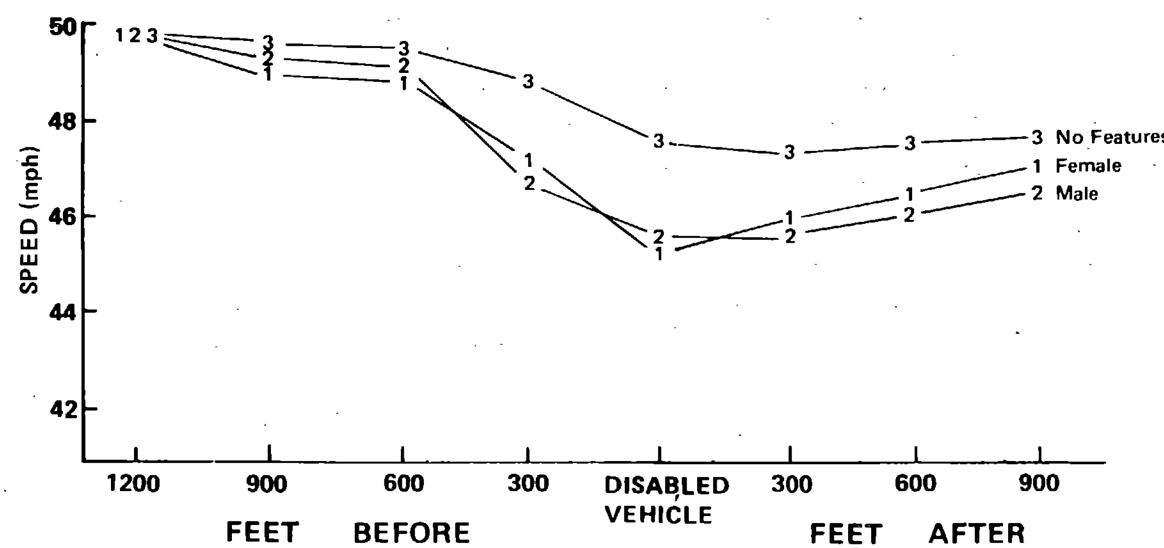
TABLE 20. Speed Profile: Female and Male Bystanders: Flashers On: Car

| KEY | EXPERIMENTAL CONDITION | 1200 FT. | | 900 FT. | | 600 FT. | | 300 FT. | | D.V. | | 300 FT. | | 600 FT. | | 900 FT. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S | X̄ | S |
| 1 | Female Bystander Flashers On | 49.8 | 1.3 | 49.2 | 2.1 | 48.4 | 2.8 | 47.2 | 3.5 | 45.2 | 6.2 | 45.9 | 4.4 | 46.6 | 4.1 | 47.1 | 4.0 |
| 2 | Male Bystander Flashers On | 49.8 | 1.3 | 49.4 | 2.2 | 48.7 | 2.9 | 46.9 | 4.0 | 45.3 | 6.1 | 45.6 | 4.7 | 46.0 | 4.6 | 46.6 | 4.9 |
| 3 | No. Features Flashers On | 49.8 | 1.3 | 49.5 | 2.5 | 49.2 | 3.2 | 48.6 | 3.7 | 47.7 | 4.1 | 47.6 | 4.0 | 47.7 | 4.2 | 47.8 | 4.5 |
| | Female vs. No. Features: Significance | | | | | .05 | | .001 | | .001 | | .001 | | .05 | | | |
| | Male vs. No. Features: Significance | | | | | | | .001 | | .001 | | .001 | | .001 | | .05 | |
| | Female vs. Male: Significance | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |

INDEPENDENT VARIABLES

| | |
|---|---|
| √ | CAR |
| | TRUCK |
| √ | TWO-LANE |
| | FOUR-LANE |
| √ | STEEP GRADE |
| | SLIGHT GRADE |
| √ | DAYLIGHT |
| | NIGHT |

1mph = 1.6kph
1ft = .3m



## Disabled Vehicle Condition - Raised Hood and Raised Trunk: Car Only

The hypothesis tested was that certain situational cues (such as a raised hood or a raised trunk) would reduce the accidental potential at the disabled vehicle. Conditions with the disabled car having either the hood up or the trunk up were tested. Data were collected under daylight conditions only, with no bystander visible. The hood-up condition produced a significant reduction in speed at the disabled vehicle in only one of the eight test situations (flashers-on and flashers-off combined, Table 21). However, two additional situations showed a significant speed reduction several traps after the disabled vehicle. Although both the hood-up and trunk-up conditions did tend to reduce both the Lane 1 speed at the disabled vehicle and the Lane 1 mean speed, the differences were not consistent across test situations or very large in magnitude. No consistent difference between the hood-up or trunk-up conditions were apparent. A slight additive effect of combining hood-up or trunk-up with the flashers-on condition is apparent. More significant Lane 1 speed reductions occurred in the flashers-on condition. Lateral placement changes were not very large and significant in only two of the situations. Both of the significant lateral placement changes occurred in the trunk-up condition. The negative values indicate that passing vehicles drove slightly further from the disabled vehicle when the trunk was raised.

One finding from the raised hood and trunk tests is that the drivers of approaching vehicles respond slightly differently to a vehicle on the shoulder with either its hood or trunk raised than they do to the vehicle alone. However, the effect is so small that it is not clear whether the hypothesis can be accepted or rejected. Perhaps the more important finding is that the instrumentation that was used and the dependent measures that were developed can actually quantify such a small change in behavior.

TABLE 21.

Significance Level Summary:
Hood Up and Trunk Up, Car

**Comparison:** HOOD UP VS. NO FEATURES
**Condition:** DISABLED CAR

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | +.2 | X | +.5 | X | 0 | X | −.5 | X | −1.3 | X | 0 | X |
| | | Slight | ● | X | ● | X | ● | X | ● | X | ● | X | ● | X |
| | 4 Lane | Steep | −1.3 | +.8 | −.6 | +.3 | +.1 | ● | −1.9 | −1.3 | −1.4 | −1.2 | −.1 | −.3 |
| | | Slight | −.2 | +.2 | −.6 | −.8 | −.3 | ● | +.1 | +1.7 | +.1 | +.7 | 0 | −.5 |
| NIGHT | 2 Lane | Steep | | X | | X | | X | | X | | X | | X |
| | | Slight | | X | | X | | X | | X | | X | | X |
| | 4 Lane | Steep | | | | | | | | | | | | |
| | | Slight | | | | | | | | | | | | |

**Comparison:** TRUNK UP VS. NO FEATURES
**Condition:** DISABLED CAR

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | +1.8 | X | +1.1 | X | −.4 | X | −1.8 | X | −1.2 | X | +.1 | X |
| | | Slight | ● | X | ● | X | ● | X | ● | X | ● | X | ● | X |
| | 4 Lane | Steep | −1.2 | −1.3 | −.6 | −.7 | −.3 | +.3 | −1.0 | +2.6 | −.8 | −.6 | −.4 | ● |
| | | Slight | 0 | +.3 | −.2 | +.2 | −.4 | +.2 | −.6 | +2.0 | −.5 | +1.3 | −.2 | 0 |
| NIGHT | 2 Lane | Steep | | X | | X | | X | | X | | X | | X |
| | | Slight | | X | | X | | X | | X | | X | | X |
| | 4 Lane | Steep | | | | | | | | | | | | |
| | | Slight | | | | | | | | | | | | |

**Comparison:** HOOD UP VS. TRUNK UP
**Condition:** DISABLED CAR

| | | | FLASHERS OFF | | | | | | FLASHERS ON | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Speed at D.V. | | Mean Speed | | Lat. Placement | | Speed at D.V. | | Mean Speed | | Lat. Placement | |
| | | | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 | Lane 1 | Lane 2 |
| DAY | 2 Lane | Steep | −1.6 | X | −.6 | X | +.4 | X | +1.3 | X | −.1 | X | −.1 | X |
| | | Slight | ● | X | ● | X | ● | X | ● | X | ● | X | ● | X |
| | 4 Lane | Steep | −.1 | +2.1 | 0 | +1.1 | +.4 | ● | −.9 | −1.1 | −.6 | −.6 | +.3 | ● |
| | | Slight | −.2 | −.1 | −.4 | −1.0 | +.1 | ● | +.7 | −.3 | −.6 | −.6 | +.2 | −.5 |
| NIGHT | 2 Lane | Steep | | X | | X | | X | | X | | X | | X |
| | | Slight | | X | | X | | X | | X | | X | | X |
| | 4 Lane | Steep | | | | | | | | | | | | |
| | | Slight | | | | | | | | | | | | |

No night data was collected on the hood up or trunk up conditions.
● Indicates no data available. Shaded values are significant, 0.05, or greater.
X Indicates not applicable comparison. D.V. indicates disabled vehicle
Speed Differences are shown in miles per hour (1mph = 1.61 kph)
Lateral Placement Differences are shown in feet (1 ft = 0.3 m)

## Disabled Vehicle Conditions - Relative Differences

The preceding sections have addressed the effects of the various disabled vehicle conditions including flashers, headlights, flares, triangles, bystanders, and the raised hood and trunk. This subsection groups some of the data for these conditions so that comparisons of the relative effects of the conditions can be made. Table 22 summarizes the effects of the various conditions for the flashers-on test and the flashers-off test. Differences in speed at the disabled vehicle are shown. The comparisons being made are shown in the left-most column. The rows represent flashers-on and flashers-off tests for the eight site-specific situations. Within each cell the relative speed change (in mph) is indicated. The relative speed change is the result of subtracting the mean speed of the first group in the comparison (i.e., headlights) from the mean speed of the second group (i.e., no features). Thus, the -2.4 in the first column, upper-most entry indicates that vehicles passing the disabled vehicle were going 2.4 mph (3.9 kph) slower when flares were displayed than when no features were present. The shaded values are significant at the 0.05 level (F-test).

Table 22 shows that the various conditions (headlights, flares, triangles) were generally less effective when the disabled truck is compared to the disabled car. Almost without exception, flares produced a larger speed reduction than any of the other conditions at the disabled car. For the disabled truck, flares were also far more effective than triangles. In only one case, in the flashers-on tests, did triangles have a greater effect.

TABLE 22.

Speed Reduction at Disabled Vehicle:
Disabled Vehicle Features Under
Flashers On and Flashers Off Conditions

| Light Condition | Day | | | | | | | | Night | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Lanes | Two Lane | | | | Four Lane | | | | Two Lane | | | | Four Lane | | | |
| Grade | Steep | | Slight | | Steep | | Slight | | Steep | | Slight | | Steep | | Slight | |
| Comparison / Flasher Condition | On | Off | On | Off | On | Off | On | Off | On | Off | On | Off | On | Off | On | Off |
| CAR ONLY | | | | | | | | | | | | | | | | |
| Headlights vs. No Features | | | | | | | | | -1.9 | -.3 | -2.5 | +4.6 | -1.7 | -2.3 | -2.0 | -3.3 |
| Flares vs. No Features | -2.4 | -4.1 | -3.3 | -2.1 | -2.9 | -4.1 | -1.8 | -1.8 | -5.3 | -7.3 | -6.3 | -7.3 | -3.2 | -6.6 | -5.0 | -3.2 |
| Triangles vs. No Features | -1.5 | -2.2 | .0 | -1.3 | -1.6 | -.7 | -.7 | -.6 | -.9 | -2.3 | -3.1 | ● | +2.0 | ● | -2.3 | -.9 |
| Flares vs. Triangles | -.9 | -1.9 | -3.3 | -.8 | -1.3 | -3.4 | -1.1 | -1.2 | -4.4 | -5.0 | -3.2 | ● | -5.2 | ● | -2.7 | -2.3 |
| Female vs. No Features | -2.5 | -4.7 | -2.0 | -1.4 | -1.2 | 1.3 | -.9 | -.6 | | | | | | | | |
| Male vs. No Features | -2.4 | -3.1 | -1.0 | -1.1 | -2.2 | -2.8 | -.6 | -.1 | | | | | | | | |
| Male vs. Female | -.1 | -1.6 | -1.0 | .3 | -1.0 | +1.5 | -.3 | -.5 | | | | | | | | |
| Hood Up vs. No Features | -.5 | +.2 | ● | ● | -1.9 | -1.3 | +.1 | -.2 | | | | | | | | |
| Trunk Up vs. No Features | -1.8 | +1.8 | ● | ● | -1.0 | 1.2 | -.6 | .0 | | | | | | | | |
| Hood vs. Trunk | +1.3 | -1.6 | ● | ● | -.9 | -.1 | +.7 | -.2 | | | | | | | | |
| TRUCK ONLY | | | | | | | | | | | | | | | | |
| Headlights vs. No Features | | | | | | | | | -2.3 | -.9 | -1.2 | -1.6 | ● | -3.9 | -.3 | -1.6 |
| Flares vs. No Features | -.1 | -2.0 | -.9 | -1.1 | -1.0 | -.1 | -.3 | -.8 | -5.0 | -4.8 | -2.1 | 3.8 | ● | -4.1 | -1.8 | -4.6 |
| Triangles vs. No Features | -.2 | -.2 | -.3 | -.1 | .0 | +.4 | -.3 | -.3 | -2.2 | -1.2 | +1.0 | -2.3 | ● | +.4 | -.9 | -1.6 |
| Flares vs. Triangles | +.1 | -1.8 | -.6 | -1.0 | -1.0 | -.5 | .0 | -.5 | -2.8 | -3.6 | -3.1 | -1.5 | -2.6 | -4.5 | -.9 | -2.9 |

Legend: Shaded cells indicate significant difference, .05 level. ● Indicates no data. Values shown are the mean differences computed by subtracting the mean of the first condition in each comparison from the mean of the second condition in the comparison, *i.e.* "No features" mean minus "headlights" mean.

Table 23 is identical to the previous table except that the dependent measure shown is the reduction in mean speed in Lane 1. The speed differences indicated are generally smaller than the speed at disabled vehicle differences shown in the previous table. They are also somewhat more stable, or consistent, across the various situations for a given disabled vehicle comparison. As was the case with the speed of the disabled vehicle table, flares were the most effective condition. The disabled car conditions involving a bystander or a raised hood or trunk were not as effective in reducing the Lane 1 mean speed as they were at affecting the speed at the disabled vehicle.

The data presented in Table 22 are summarized in Table 24. To facilitate comparisons, flashers-on versus flashers-off data are shown in the left-hand third of the table. The values shown are the mean values for the flashers-off condition minus the mean values for the flashers-on condition. Thus, a negative value indicates a slower speed for the flashers-on condition. Values are shown for the car only, no features condition; the truck only, no features condition; and the other disabled vehicle conditions, flares, triangles, etc. The mean values were computed by taking the average across all four sites. The right-hand two-thirds of the table show the effect of the various conditions listed. These values were obtained by subtracting the mean speed for each condition from the "no features" mean. The effect of each disabled vehicle condition is shown for both the flashers-on (middle) and flashers-off (right side) tests. Mean differences for day, night, and day and night combined are shown. The largest flashers-on versus flashers-off effect was found when the headlights were combined with flashers. This difference, 2.6 mph (4.2 kph), was larger than the 2.0 mph (3.2 kph) reduction found with flashers alone. For the disabled truck, no further reduction in speed was attributable to the flashers in the headlights-on tests. The

TABLE 23.

Mean Speed Reduction, Lane 1, by Test Situation
Disabled Vehicle Features, Under Flashers On
and Flashers Off Conditions

| Light Condition | Day | | | | | | | | Night | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Lanes | Two Lane | | | | Four Lane | | | | Two Lane | | | | Four Lane | | | |
| Grade | Steep | | Slight | | Steep | | Slight | | Steep | | Slight | | Steep | | Slight | |
| Comparison / Flasher Condition | On | Off | On | Off | On | Off | On | Off | On | Off | On | Off | On | Off | On | Off |
| CAR ONLY | | | | | | | | | | | | | | | | |
| Headlights vs. No Features | | | | | | | | | 1.2 | −1.5 | −2.2 | +3.6 | −.7 | −1.2 | −1.1 | −2.1 |
| Flares vs. No Features | −1.0 | −1.5 | −1.4 | −.9 | −1.4 | −2.2 | −.7 | −.7 | −2.8 | −3.5 | −4.4 | −1.9 | −.1 | −3.0 | −2.1 | −2.1 |
| Triangles vs. No Features | −.8 | −1.0 | +.2 | −.7 | −.7 | −.4 | −.5 | −.5 | −.3 | −1.3 | −2.2 | ● | +1.8 | ● | −1.4 | −.7 |
| Flares vs. Triangles | −.2 | −.5 | −1.6 | −.2 | −.7 | −1.8 | −.2 | −.2 | −2.5 | −2.2 | −2.2 | ● | −1.9 | ● | −.7 | −1.4 |
| Female vs. No Features | −1.0 | −1.7 | −.6 | −.7 | −.6 | −.3 | −.4 | −.2 | | | | | | | | |
| Male vs. No Features | −1.1 | −1.6 | −.2 | −.2 | −1.1 | −1.2 | −.2 | .0 | | | | | | | | |
| Male vs. Female | +.1 | −.2 | −.4 | −.6 | +.5 | +.9 | −.2 | −.2 | | | | | | | | |
| Hood Up vs. No Features | −1.3 | +.5 | ● | ● | −1.4 | −.6 | +.1 | −.6 | | | | | | | | |
| Trunk Up vs. No Features | −1.2 | +1.1 | ● | ● | −.8 | −.6 | −.5 | .2 | | | | | | | | |
| Hood vs. Trunk | −.1 | −.6 | ● | ● | −.6 | .0 | +.6 | −.4 | | | | | | | | |
| TRUCK ONLY | | | | | | | | | | | | | | | | |
| Headlights vs. No Features | | | | | | | | | −1.2 | .7 | −.8 | −.6 | ● | −2.8 | −.1 | −1.1 |
| Flares vs. No Features | +.1 | −1.9 | −.4 | −.4 | −.2 | −.1 | −.1 | −.4 | −2.7 | −2.8 | −1.0 | −2.6 | ● | −1.9 | −.2 | −2.3 |
| Triangles vs. No Features | .0 | −.2 | −.5 | −.1 | +.2 | +.1 | .0 | −.1 | −1.4 | −.8 | +.7 | −1.4 | ● | .0 | −.2 | −1.0 |
| Flares vs. Triangles | +.1 | −1.7 | +.1 | −.3 | −.4 | −.2 | −.1 | −.3 | −1.4 | −2.2 | −1.7 | −1.2 | −1.5 | −1.9 | .0 | −1.3 |

Legend: Shaded cells indicate significant difference, .05 level. ● Indicates no data. Values shown are the mean differences computed by subtracting the mean of the first condition in each comparison from the mean of the second condition in the comparison, i.e. "No features" mean minus "headlights" mean.

Table 24.

Speed Reduction at Disabled Vehicle, Averages Across All Test Situations

| | Condition | Flashers OFF Minus Flashers ON Difference | | | No Features Minus Condition Difference | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Flashers ON | | | Flashers OFF | | |
| | | Day | Night | Day and Night | Day | Night | Day and Night | Day | Night | Day and Night |
| Disabled Car | Car only, no features | –.7 | –2.0 | –1.3 | N/A | N/A | N/A | N/A | N/A | N/A |
| | Headlights | ● | –2.6 | ● | ● | –2.0 | ● | ● | –2.0 | ● |
| | Flares | –.3 | +.3 | 0 | –2.6 | –5.0 | –3.8 | –3.0 | –6.1 | –4.6 |
| | Triangles | –.5 | –.7 | –.6 | –1.0 | –1.1 | –1.0 | –1.2 | –1.6 | –1.3 |
| | Female bystander | –.4 | ● | ● | –1.7 | ● | ● | –1.4 | ● | ● |
| | Male bystander | –.2 | ● | ● | –1.6 | ● | ● | –1.8 | ● | ● |
| | Hood up | –1.1 | ● | ● | –.8 | ● | ● | –.4 | ● | ● |
| | Trunk up | –2.1 | ● | ● | –1.1 | ● | ● | –.6 | ● | ● |
| Disabled Truck | Truck only, no features | –.4 | –1.1 | –.7 | N/A | N/A | N/A | N/A | N/A | N/A |
| | Headlights | ● | .0 | ● | ● | –1.3 | ● | ● | –2.0 | ● |
| | Flares | .0 | +.3 | +.2 | –.6 | –3.0 | –1.6 | –1.0 | –3.2 | –1.9 |
| | Triangles | –.6 | –.6 | –.6 | –.2 | –.7 | –.4 | –.1 | –1.2 | –.6 |

Values shown are average speed changes across the eight test situations.

N/A Indicates that data comparison is "not applicable"

● Indicates that data was not collected, i.e. on the "bystander" condition at night.

headlights-on condition reduced speed an average of 2.0 mph (3.2 kph) in both the flashers-on and flashers-off tests. Although less than the reduction attributable to the flares, the headlights alone were more effective than triangles in both the flashers-on and flashers-off tests. This same relationship between the triangles and headlights was also true for the disabled truck. However, for the truck tests the flashers were not as effective as the headlights.

Table 25 is a similar summarization of the Lane 1 mean speed data across all of the disabled vehicle conditions. For the disabled car test the same relative relationships seem to hold. Triangles were less effective than headlights alone, but headlights and flashers had about the same effect. For the disabled truck test, triangles were more effective than headlights (in the flashers-off condition) which, in turn, were more effective than the flashers. The absolute amounts of these differences (-1.1 to -0.7) were relatively small.

TABLE 25.

Mean Speed Reductions, Lane 1, Averages Across All Test Situations

| | Condition | Flashers OFF Minus Flashers ON Difference | | | No Features Minus Condition Difference | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Flashers ON | | | Flashers OFF | | |
| | | Day | Night | Day and Night | Day | Night | Day and Night | Day | Night | Day and Night |
| Disabled Car | Car only, no features | −.4 | −1.6 | −.9 | N/A | N/A | N/A | N/A | N/A | N/A |
| | Headlights | ● | −1.6 | ● | ● | −.7 | ● | ● | −1.6 | ● |
| | Flares | −.2 | −.4 | −.3 | −1.1 | −2.4 | −1.7 | −1.3 | −2.6 | −2.0 |
| | Triangles | −.2 | −.6 | −.3 | −.5 | −.5 | −.5 | −.7 | −1.0 | −.8 |
| | Female bystander | −.3 | ● | ● | −.7 | ● | ● | −.7 | ● | ● |
| | Male bystander | −.3 | ● | ● | −.7 | ● | ● | −.7 | ● | ● |
| | Hood up | −1.0 | ● | ● | −.9 | ● | ● | −.2 | ● | ● |
| | Trunk up | −1.3 | ● | ● | −.8 | ● | ● | +.2 | ● | ● |
| Disabled Truck | Truck only, no features | −.3 | −.7 | −.4 | N/A | N/A | N/A | N/A | N/A | N/A |
| | Headlights | | +.2 | | | −.7 | | | −1.0 | |
| | Flares | +.3 | +.4 | +.3 | −.2 | −1.0 | −.6 | −.7 | −.6 | −1.6 |
| | Triangles | −.2 | −.3 | −.3 | −.1 | −.3 | −.2 | −.1 | −1.1 | −.5 |

Values shown are average speed changes across the eight test situations.

## Summary and Conclusions

A variety of techniques to warn approaching motorists of the presence of a disabled vehicle were evaluated. The Traffic Evaluator System (TES), using a series of unobtrusive tapeswitches, monitored the behavior of vehicles as they approached a disabled vehicle parked on the shoulder.

The procedures evaluated included standard four-way flashers with either red or amber lights. The other techniques included flares, warning triangles, bystanders at the vehicle, raised hood or trunk on the vehicle; these were tested under both the flashers-on and flashers-off conditions. Tests were conducted using both a car and a truck as the disabled vehicle under both day and night conditions. Four experimental sites combining two- and four-lane and steep and slight grades were used.

The following summarizes the results of the evaluation of each of the conditions:

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

*Headlights Displayed.* There is strong evidence that displaying parking lights (truck) increases the safety potential. The effect is further enhanced when headlights are 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 vehicles. 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 headlights. 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. 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 in 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 reductions 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 26 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 each of the eight experimental situations. 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 to safety attributable to the use of four-way flashers is seen in the speed profiles of the traffic stream as it approaches and passes the disabled vehicle. Figures 9 and 10 (see pages 65 and 66) showed the speed profiles for each of the eight experimental situations. 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

TABLE 26.

Safety Implications of Four-Way Flashers

**SAFETY IMPLICATIONS**
**REDUCTION IN SPEED, AT THE DISABLED VEHICLE**

| EXPERIMENTAL SITUATION / TEST CONDITION | 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**

| EXPERIMENTAL SITUATION / TEST CONDITION | 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

react to it. The differences between the speed profiles for the steep grades and the slight grades suggest that the 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.

# III. SLOW-MOVING VEHICLE STUDY

## Introduction

This section presents the data collected on the behavior of drivers overtaking a slow-moving vehicle. The overall experimental design was discussed in detail in Section I. The study involved introducing a slow-moving vehicle (either a car or a tractor-trailer) into the traffic stream. This introduction was timed so that drivers of overtaking vehicles could not see the test vehicle until it had accelerated to a preselected speed of either 30 mph (48.3 kph) or 40 mph (64.4 kph) and was approximately halfway through an instrumented section of roadway. At that point, the overtaking vehicle (subject vehicle) was already in the instrumented array. In order to determine the effectiveness of four-way flashers on modifying a driver's overtaking behavior, tests were conducted across a variety of experimental conditions:

- Red four-way flashers
- Amber four-way flashers
- Slow-moving car: 30 mph (48.3 kph)
- Slow-moving truck: 30 mph (48.3 kph)
- Slow-moving car: 40 mph (64.4 kph)
- Slow-moving truck: 40 mph (64.4 kph)

Since data were collected under both day and night conditions at each of four experimental sites, a total of eight test situations are included in the discussion that follows.

The term "condition" is used to describe the various independent variables being evaluated, i.e., car, truck, 30 mph (48.3 kph), 40 mph (64.4 kph). The term "situation" is used to describe the site-specific situations, i.e., day, two-lane, steep grade.

Dependent measures were developed from the vehicle speed, vehicle headway, and vehicle tailway data:

- Distance to Initial Reaction Point (IRD): The distance (in feet [meters]) that the overtaking vehicle was behind the test vehicle when a speed reduction of 1 mph (1.6 kph) between two speed traps (300 feet [90 m]) was first observed. The point where the 1 mph (1.6 kph) reduction occured was the initial reaction point (IRP). Since the overtaking vehicles were typically traveling approximately 50 mph (80.5 kph), this amounted to a 2% reduction in speed. The higher the IRD, the further the overtaking vehicle was from the test vehicle when the slowing down began. Higher IRD values are indicative of more cautious and presumably safer behavior.

- Speed at Initial Reaction Point (IRS): The speed (in mph [kph]) of the overtaking vehicle at the initial reaction point (IRP). Lower IRD values are indicative of a slight slowing on the part of the approaching vehicle.

- Time to Collision at IRP (TTC): The time (in seconds) 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 IRP. A higher time to collision value is indicative of safer driving behavior.

- Maximum Deceleration (MD): The maximum deceleration rate (in feet [meters] per second) exhibited by the overtaking vehicle. Higher values are indicative of a less gradual slowing and a less cautious overtaking behavior.

- Distance at Maximum Deceleration (DMD): The distance (in feet [meters]) that the overtaking vehicle was behind the test vehicle when its maximum deceleration occurred. The DMD is usually less than the IRD and indicates where the greatest slowing down occurred. Higher DMD values are indicative of more cautious overtaking behavior.

- Speed at Maximum Deceleration (SMD): The speed (in mph [kph]) of overtaking vehicles at the point of maximum deceleration.

- Passer, Speed at Start of Pass - Speed at Lane Change (PSLC): The speed (in mph [kph]) of overtaking vehicles, which passed the test vehicle, when the driver of the overtaking vehicle changed lanes to pass.

- Passer Headway Distance at Lane Change (PDLC): The distance (in feet [meters]) that the overtaking vehicle was behind the test vehicle when the overtaking vehicle changed lanes to pass.

For each dependent measure, the mean, standard deviation, and an F-test value were computed. These values along with the minimum, 15th percentile, median, 85th percentile, and maximum values were summarized in comparison data tables to compare the values across two experimental conditions.

In addition, a computer-generated graphic display was prepared for each condition tested. This display plotted the speed of the overtaking vehicle as a function of its distance behind the test vehicle.

The definitions of the various dependent measures were based on what constituted relevant behavior on the part of the overtaking vehicle drivers. In order to qualify as "a vehicle of interest," an overtaking vehicle driver had to make some response to the test vehicle ahead. After examining a number of individual vehicle records, it was determined that a 1 mph (1.6 kph) speed change was greater than the normal speed variability found in the traffic stream and, hence, could be considered a reasonable indication of the overtaking vehicle driver's initial response to the test vehicle. Overtaking vehicle drivers do one of two things when closing on the test vehicle: they can slow down and follow or they can pass the test vehicle.

In the two-lane situation, the majority of the "vehicles of interest" (352 of 430) slowed down and followed the vehicle out of the array (a nonpasser). Since the behavior of those vehicles that passed the test vehicle was dependent on "passing opportunity" and on the presence or absence of four-way flashers, the behavior of nonpassers is the major concern in the two-lane situation. A discussion of passing opportunity and the effect of flasher usage on passing behavior is presented later in this section. The last two dependent measures, passer speed at lane change and passer distance at lane change, were taken on all passing vehicles regardless of whether they showed sufficient speed reduction to identify the initial reaction point.

In the four-lane situations, the opposite is true. Slightly more than half of the "vehicles of interest" (132 of 246) that showed the 1 mph (1.6 kph) decrease passed the test vehicle. Another 138 approaching vehicles passed without reducing their speed. Since nonpassers in the four-lane situation did not pass because of (1) a lack of opportunity to move into the second lane or (2) an inability to maintain speed on the grade (especially in the case of trucks), they were of less interest than vehicles that did approach and subsequently pass the test vehicle.

The first six dependent measures for all two-lane sites were derived for the approaching vehicles that did not pass the test vehicle. The passer speed at lane change and passer distance at lane change measures were derived for those approaching vehicles that did pass. The first six dependent measures for all four-lane sites were derived from the approaching vehicles that showed a 1 mph (1.6 kph) speed decrease but subsequently passed the test vehicle. The passer measures include these vehicles plus those that did not slow down the 1 mph (1.6 kph) required for IRP determination.

In addition to the results of the study of the effect of flashers, the results of two additional analyses are described in this section. The first analysis concerns the effect of flashers on passing behavior at the two-lane sites. The second analysis is a comparison of deceleration rates found in response to the flasher conditions and the deceleration rates determined in a field evaluation of coasting behavior.

## Red vs. Amber Flashers

The relative effectiveness of red vs. amber four-way flashers was compared. The wiring system of the test vehicle (car only) was modified so that the four-way flashers activated a bulb behind either a red or an amber lens. Half the test runs were made with the amber flashers and half with the red flashers. The order of presentation was randomized. The effectiveness was tested for each of eight test situations.

Both the 30 and 40 mph (48.3 and 64.4 kph) slow-moving vehicle conditions were tested in all eight situations. Table III-1 summarizes the safety implications of each of the eight MOEs for the eight situations. In about half of all the comparisons made, red flashers were more effective than amber flashers. In the other half of the comparisons, amber flashers were more effective. Virtually none of the differences found were statistically significant. There were no consistent differences in effectiveness attributable to the day/night conditions. No patterns were observed in the conditions for which red or amber flashers were more effective. Although Mortimer (1973) reported red to be somewhat more effective than amber during daylight and amber to be clearly more effective than red at night, these results do not support his conclusions. Because of the lack of consistent effects, all future comparisons of "flashers-on" include a combination of both red and amber flasher conditions.

## TABLE 27

### Safety Implications: Red vs. Amber Flashers

| Measure of Effectiveness \ Test Situation | | DAY | | | | NIGHT | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2 LANE | | 4 LANE | | 2 LANE | | 4 LANE | |
| | | Steep | Slight | Steep | Slight | Steep | Slight | Steep | Slight |
| Initial Reaction Distance | 30 mph | – | + | ● | + | + | + | ● | ● |
| | 40 mph | – | + | ● | + | + | – | ● | + |
| Initial Reaction Speed | 30 mph | + | – | ● | + | – | – | ● | ● |
| | 40 mph | – | – | ● | – | – | + | ● | – |
| Time to Collision | 30 mph | – | + | ● | + | – | – | ● | ● |
| | 40 mph | – | + | ● | + | ● | – | ● | – |
| Maximum Deceleration | 30 mph | – | + | ● | 0 | – | ● | ● | ● |
| | 40 pmh | + | + | ● | + | ● | + | ● | – |
| Distance at Maximum Deceleration | 30 mph | – | + | ● | + | + | + | ● | ● |
| | 40 mph | – | + | ● | – | + | – | ● | + |
| Speed at Maximum Deceleration | 30 mph | + | + | ● | + | – | – | ● | + |
| | 40 mph | – | – | ● | 0 | – | + | ● | – |
| Passer, Speed at Lane Change | 30 mph | + | ● | ● | – | + | ● | ● | + |
| | 30 mph | – | ● | ● | – | ● | ● | ● | – |
| Passer, Distance at Lane Change | 30 mph | – | ● | ● | – | – | ● | ● | ● |
| | 40 mph | – | ● | ● | + | ● | ● | ● | ● |

+ Indicates red more effective; - indicates amber more effective.
o Indicates no differences between effectiveness of red and amber.
● Indicates no data available.

## Effectiveness of Four-Way Flashers

The next part of this section addresses the effectiveness of four-way flashers under the full range of test conditions. Two types of exhibits are used to present the data. The first type, the Dependent Measures Summary, shows the difference between the means for each of the eight dependent measures. The differences were computed by subtracting the mean value for the flashers-off condition from the mean value for the flashers-on condition. The next three exhibits contain data for the eight test situations:

- 30 mph (48.3 kph) slow-moving vehicle, two-lane, steep grade
- 30 mph (48.3 kph) slow-moving vehicle, two-lane, slight grade
- 30 mph (48.3 kph) slow-moving vehicle, four-lane, steep grade
- 30 mph (48.3 kph) slow-moving vehicle, four-lane, slight grade
- 40 mph (64.4 kph) slow-moving vehicle, two-lane, steep grade
- 40 mph (64.4 kph) slow-moving vehicle, two-lane, slight grade
- 40 mph (64.4 kph) slow-moving vehicle, four-lane, steep grade
- 40 mph (64.4 kph) slow-moving vehicle, four-lane, slight grade.

These three exhibits represent different combinations of the basic experimental conditions:

Daytime: Car, Truck, Car and Truck (Table 28)
Nighttime: Car, Truck, Car and Truck (Table 29)
Day and Night: Car and Truck (Table 30)

The second type of exhibit plots the mean and standard deviation for two of the dependent measures. Initial Reaction Distance (IRD) and Time to Collision (TTC) plots are shown. These measures were selected because they most clearly show the effects of the flashers and because they have obvious implications as a measure of improvement in safety. These flashers-on vs. flashers-off comparisons are grouped for the same set of eight test situations.

Daylight Conditions:
Car, Truck, Car and Truck

Table 28 is the dependent measures summary for the day test condition and contains car only, truck only, and car and truck combined data. The car only, flashers-on condition produced larger (as indicated by a positive difference in mean value) initial reaction distances in six of the eight test situations. Although the positive differences varied from +21.6 to +138.9 feet (+6.5 to 41.7 m), none were statistically significant. The flashers produced lower speeds at the IRP in six of the eight situations. Only the two-lane, steep grade site with the 40 mph (64.4 kph) slow-moving car produced a significant reduction. Although the time to collision values were higher (in seven of eight situations) with the flashers on, none of the differences were significant. The passer speed at lane change resulted in a significant effect, at the four-lane, slight grade site with a 40 mph (64.4 kph) slow-moving vehicle. The remaining four measures confirm flasher effectiveness, but are not statistically significant.

TABLE 28: Dependent Measures Summary: Mean Differences*, Day

**CONDITION:** Day: Car, Truck, Car & Truck

**COMPARISION:** Flashers On vs. Flashers Off

| Condition | DEPENDENT MEASURE \ SITUATIONS | 30 MPH | | | | 40 MPH | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2-LANE | | 4-LANE | | 2-LANE | | 4-LANE | |
| | | STEEP | SLIGHT | STEEP | SLIGHT | STEEP | SLIGHT | STEEP | SLIGHT |
| CAR | Initial Reaction Distance (ft.) | +106.1 | +138.9 | - 61.7 | + 21.6 | + 34.6 | - 1.3 | +108.8 | + 72.1 |
| | Speed at IRP (mph) | - 1.1 | + 1.7 | - 2.6 | - 0.4 | - 3.6 | - 1.4 | - 5.1 | + 0.4 |
| | Time to Collision at IRP (sec) | + 6.4 | + 5.0 | + 3.1 | + 1.2 | + 7.8 | + 3.3 | - 0.1 | + 3.9 |
| | Maximum Deceleration (ft/sec/sec) | - 0.6 | - 0.5 | - 0.3 | + 0.2 | - 0.1 | - 0.5 | + 0.1 | + 4.3 |
| | Distance at Max.Dec. (ft) | +153.7 | + 55.4 | - 49.9 | - 5.0 | + 75.9 | + 42.7 | + 69.0 | + 44.5 |
| | Speed at Max. Dec. (mph) | + 1.5 | - 2.0 | - 2.1 | - 0.9 | - 1.8 | + 0.2 | - 5.8 | + 1.2 |
| | Passer, Speed at Lane Change (mph) | + 4.6 | ● | - 6.0 | - 2.8 | + 0.3 | - 0.4 | - 6.2 | - 3.3 |
| | Passer, Distance at Lane Change (ft) | + 28.4 | ● | +124.5 | + 14.0 | +157.4 | - 26.4 | + 46.4 | + 67.1 |
| TRUCK | Initial Reaction Distance (ft) | +108.6 | + 31.0 | ● | ● | + 48.6 | +130.9 | - 57.9 | +168.8 |
| | Speed at IRP (mph) | + 0.5 | - 0.7 | ● | ● | - 0.6 | 0.0 | + 2.6 | - 1.1 |
| | Time to Collision at IRP (sec) | + 2.3 | + 2.2 | ● | ● | + 9.2 | + 7.7 | - 7.1 | + 6.2 |
| | Max. Deceleration (ft/sec/sec) | - 0.5 | - 0.1 | ● | ● | 0.0 | - 0.4 | + 0.8 | - 0.3 |
| | Distance at Max. Dec. (ft) | + 68.6 | + 8.5 | ● | ● | + 69.9 | +114.3 | - 24.1 | +207.5 |
| | Speed at Max. Dec. (mph) | - 0.1 | - 2.4 | ● | ● | + 0.9 | + 0.1 | + 4.7 | - 0.2 |
| | Passer, Speed at Lane Change (mph) | ● | ● | + 4.8 | + 1.3 | - 3.1 | ● | - 0.4 | - 1.0 |
| | Passer, Distance at Lane Change (ft) | ● | ● | +139.4 | + 89.9 | - 11.6 | ● | + 16.5 | + 18.2 |
| BOTH | Initial Reaction Distance (ft) | +121.2 | + 91.4 | - 28.8 | + 11.5 | + 40.6 | + 50.4 | + 32.4 | +113.3 |
| | Speed at IRP (mph) | + 0.5 | + 1.3 | + 0.6 | - 0.7 | - 2.5 | - 0.9 | - 0.6 | - 0.2 |
| | Time to Collision at IRP (sec) | + 3.8 | + 3.1 | + 1.8 | + 0.8 | + 8.3 | + 5.4 | - 3.9 | + 4.7 |
| | Max. Deceleration (ft/sec/sec) | - 0.5 | - 0.2 | - 0.5 | + 0.2 | - 0.2 | - 0.6 | + 0.5 | + 2.3 |
| | Distance at Max. Dec. (ft) | +108.8 | + 34.7 | - 43.3 | - 11.0 | + 74.0 | + 69.7 | + 33.9 | +111.8 |
| | Speed at Max. Dec. (mph) | + 1.1 | - 1.4 | + 0.1 | - 1.1 | - 0.8 | + 0.1 | 0.4 | + 0.5 |
| | Passer, Speed at Lane Change (mph) | + 3.9 | ● | - 1.4 | - 1.7 | - 0.9 | - 0.5 | - 2.9 | - 2.3 |
| | Passer, Distance at Lane Change (ft) | + 34.0 | ● | + 75.3 | + 41.2 | + 6.3 | - 18.9 | + 29.3 | + 44.1 |

*Mean differences computed by subtracting the flashers-off mean from the flashers-on mean.

Shaded areas indicate significant differences, F-test, $p \leq .05$.

The truck displaying four-way flashers under daylight conditions produced an increase in initial reaction distance in five of the six situations for which data are available.

Nighttime Conditions:
Car, Truck, Car and Truck

Table 29 is the dependent measures summary for the nighttime conditions. Data for the slow-moving car, the slow-moving truck, and both vehicles combined are presented. A number of the test situations are indicated as having no data (as shown by a dot). This is because at least one of the groups being compared (i.e., flashers-on or flashers-off) was too small to be used for the statistical comparisons. Although this was also true for two of the day/truck tests, it is far more evident in the nighttime tests. There are several reasons for this phenomenon. First, with less time to collect data and traffic volume being less after dark, the number of available subject vehicles was lower. Second, the approaching subject vehicles were less likely to maintain speed at night, especially at the four-lane steep site. Since the Traffic Evaluator System was used to track the subject vehicles for at least three traps at a constant speed in order to identify the IRD, this failure to maintain speed up the grade resulted in fewer vehicles with an identifiable IRD.

The data confirm what was previously described for the daylight condition. Initial reaction distances were greater in all three car test situations. Time to collision was increased in two-thirds of the car tests and all of the truck tests. The single decrease in time to collision was only 0.6 seconds, while one of the truck tests produced a positive increase that was significant at the 0.01 level. All of the subject vehicle drivers who passed the test vehicle initiated the pass sooner when the flashers were displayed.

TABLE 29: Dependent Measures Summary: Mean Differences*, Night

**CONDITION:** Night: Car, Truck, Car & Truck

**COMPARISION:** Flashers On vs. Flashers Off

| Condition | DEPENDENT MEASURE / SITUATIONS | 30 MPH | | | | 40 MPH | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2–LANE | | 4–LANE | | 2–LANE | | 4–LANE | |
| | | STEEP | SLIGHT | STEEP | SLIGHT | STEEP | SLIGHT | STEEP | SLIGHT |
| CAR | Initial Reaction Distance (ft.) | ● | ● | ● | + 80.4 | +118.7 | + 56.1 | ● | ● |
| | Speed at IRP (mph) | ● | ● | ● | − 0.7 | − 0.8 | + 0.6 | ● | ● |
| | Time to Collision at IRP (sec) | ● | ● | ● | + 1.2 | + 13.7 | − 0.6 | ● | ● |
| | Maximum Deceleration (ft/sec/sec) | ● | ● | ● | + 0.8 | + 0.2 | − 0.1 | ● | ● |
| | Distance at Max.Dec. (ft) | ● | ● | ● | +100.0 | +149.8 | + 7.2 | ● | ● |
| | Speed at Max. Dec. (mph) | ● | ● | ● | + 0.6 | + 1.1 | 0.0 | ● | ● |
| | Passer, Speed at Lane Change (mph) | + 4.6 | ● | − 3.3 | + 1.3 | ● | ● | ● | − 4.9 |
| | Passer, Distance at Lane Change (ft) | + 28.4 | ● | +329.6 | +110.9 | ● | ● | ● | +121.4 |
| TRUCK | Initial Reaction Distance (ft) | − 91.9 | +137.8 | ● | ● | + 20.6 | +130.5 | ● | ● |
| | Speed at IRP (mph) | − 7.0 | + 5.6 | ● | ● | − 2.0 | − 2.5 | ● | ● |
| | Time to Collision at IRP (sec) | + 4.6 | + 2.2 | ● | ● | + 5.5 | + 17.6 | ● | ● |
| | Max. Deceleration (ft/sec/sec) | − 1.3 | − 0.2 | ● | ● | − 0.3 | + 0.2 | ● | ● |
| | Distance at Max. Dec. (ft) | + 35.2 | +112.4 | ● | ● | + 3.9 | +192.6 | ● | ● |
| | Speed at Max. Dec. (mph) | − 3.2 | + 4.9 | ● | ● | − 2.6 | + 0.1 | ● | ● |
| | Passer, Speed at Lane Change (mph) | ● | ● | ● | ● | ● | ● | ● | + 1.1 |
| | Passer, Distance at Lane Change (ft) | ● | ● | ● | ● | ● | ● | ● | + 31.9 |
| BOTH | Initial Reaction Distance (ft) | + 11.1 | +162.6 | +265.8 | + 72.1 | + 99.4 | + 80.8 | ● | +105.5 |
| | Speed at IRP (mph) | − 4.0 | + 6.1 | + 4.8 | − 3.1 | − 1.9 | − 0.4 | ● | − 6.8 |
| | Time to Collision at IRP (sec) | + 5.8 | + 12.6 | + 4.6 | + 2.3 | + 12.2 | + 5.3 | ● | + 8.0 |
| | Max. Deceleration (ft/sec/sec) | − 0.9 | + 0.2 | − 0.2 | + 0.5 | 0.0 | 0.0 | ● | 0.0 |
| | Distance at Max. Dec. (ft) | 119.9 | +128.4 | +335.0 | + 70.2 | +121.0 | + 67.5 | ● | +118.6 |
| | Speed at Max. Dec. (mph) | − 1.1 | + 5.8 | + 5.7 | − 2.3 | − 0.3 | − 0.1 | ● | − 6.5 |
| | Passer, Speed at Lane Change (mph) | − 2.9 | ● | + 2.6 | − 0.8 | − 5.2 | ● | ● | − 1.5 |
| | Passer, Distance at Lane Change (ft) | + 29.1 | ● | +315.8 | +104.4 | − 28.1 | ● | ● | + 53.0 |

*Mean differences computed by subtracting the flashers-off mean from the flashers on mean.

Shaded areas indicate significant differences, F-test, $p \leq .05$.

When the data for cars and trucks are combined, the same trends are evident. Reaction distance was increased by the flashers in all test situations. Time to collision was also increased in all test situations. The point of maximum deceleration was always farther from the test vehicle when the flashers were on. The mean differences varied from an increase of 67.5 feet (20.3 m) to 335.0 feet (100.5 m).

## Day and Night Conditions: Car and Truck Combined

Table 30 presents the mean differences of the dependent measures for both vehicles for day and night conditions combined. The flashers-on condition increased reaction distance in all eight test situations. Differences varied from 21.9 feet (6.6 m) to 106.9 feet (32.1 m). The two-lane slight and the four-lane slight sites had differences that were significant at the 0.05 level. The mean vehicle speed at the initial reaction distance was slower in the flashers-on condition in six of the eight situations. The time to collision measure was increased by the flashers being on in all eight situations. One of these increases, at the four-lane slight site, was significant at the 0.05 level. The maximum deceleration rate was less in four of the eight situations; this difference was significant in two of those four. As was the case with the initial reaction distance, the distance at maximum deceleration was increased by the flashers in all eight test situations. The difference in mean speed at the point of maximum deceleration varied very little between the flashers-on and flashers-off conditions, ranging from a decrease of 0.1 mph (0.2 kph) to an increase of 1.2 mph (1.9 kph). Half of the differences were positive, the other half negative. The behavior of passing vehicle drivers at the four-lane sites was affected in a positive manner by the flashers. In all cases, the passing vehicle drivers initiated their pass further from the slow-moving

TABLE 30: Dependent Measures Summary Mean Differences*, Day and Night.

**CONDITION:** Day and Night: Car & Truck Combined

**COMPARISION:** Flashers On vs. Flashers Off

| Condition | DEPENDENT MEASURE / SITUATIONS | 30 MPH 2-LANE STEEP | 30 MPH 2-LANE SLIGHT | 30 MPH 4-LANE STEEP | 30 MPH 4-LANE SLIGHT | 40 MPH 2-LANE STEEP | 40 MPH 2-LANE SLIGHT | 40 MPH 4-LANE STEEP | 40 MPH 4-LANE SLIGHT |
|---|---|---|---|---|---|---|---|---|---|
| BOTH CAR & TRUCK | Initial Reaction Distance (ft) | + 94.1 | +106.9 | + 55.1 | + 21.9 | + 35.5 | + 57.9 | + 72.8 | + 97.2 |
| | Speed at IRP (mph) | − 0.9 | + 2.2 | + 1.4 | − 1.6 | − 1.1 | − 0.7 | − 1.5 | − 1.8 |
| | Time to Collision at IRP (sec) | + 4.4 | + 5.6 | + 3.2 | + 1.2 | + 7.6 | + 5.3 | + 1.4 | + 5.3 |
| | Max. Deceleration (ft/sec/sec) | − 0.6 | − 0.2 | − 0.4 | + 0.2 | 0.0 | − 0.4 | + 0.3 | + 2.0 |
| | Distance at Max. Dec. (ft) | +113.8 | + 56.7 | + 57.8 | + 7.1 | + 52.6 | + 66.6 | + 81.3 | + 96.3 |
| | Speed at Max. Dec. (mph) | + 0.4 | + 0.1 | + 1.1 | − 1.6 | − 0.1 | + 0.1 | − 0.7 | − 1.2 |
| | Passer, Speed at Lane Change (mph) | + 4.1 | + 5.8 | − 0.3 | − 1.4 | − 0.6 | + 2.9 | − 3.1 | − 2.1 |
| | Passer, Distance at Lane Change (ft) | + 34.1 | + 48.0 | +129.4 | + 60.2 | + 3.9 | + 33.3 | + 90.0 | + 46.3 |

*Mean differences computed by subtracting the flashers-off mean from the flashers-on mean.

Shaded areas indicate significant differences, F-test, $p \leq .05$.

vehicle and were going slightly slower when they started passing. Both the speed difference and the distance difference were significant in one of the eight situations.

## Measure of Effectiveness: Reaction Distance

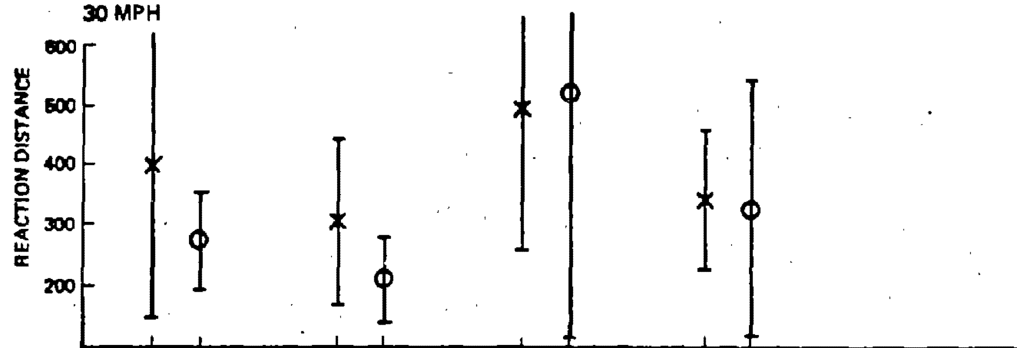
In the preceding discussion of the dependent measures summaries, the persistence of two specific dependent measures was very apparent. Reaction distance and time to collision indicated a positive safety benefit across all test situations. This section addresses the reaction distance measure; the following section will deal with time to collision. Figures 12 through 14 graphically present the reaction distance data for the full range of test conditions. The plots indicate the mean values for the flashers-on conditions (X) and for the flashers-off condition (O). An "on" and an "off" value are plotted for each site; two-lane, steep and slight; four-lane, steep and slight. The top portion of the figure presents data from the 30 mph (48.3 kph) test vehicle condition; the bottom portion from the 40 mph (64.4 kph) test vehicle condition. The bars indicate one standard deviation above and one standard deviation below the mean value. Shown in the table below each plot are the mean and standard deviations as well as the F-value and significance level of each comparison. Figure 15 shows the plots for the daylight conditions. The flashers reduced mean speed in seven of the eight situations. Figure 16 shows the plots for the night test conditions. The presence of flashers always increased the reaction distance. The day and night test conditions produced very similar results for the majority of the test situations. Figure 17 shows the combined day and night data. All eight situations showed an increase in reaction distance under the flashers-on conditions. All four two-lane conditions showed an increase in the standard deviation under the flashers-on condition.

MEASURE: Reaction Distance

CONDITION: Day: Car and Truck

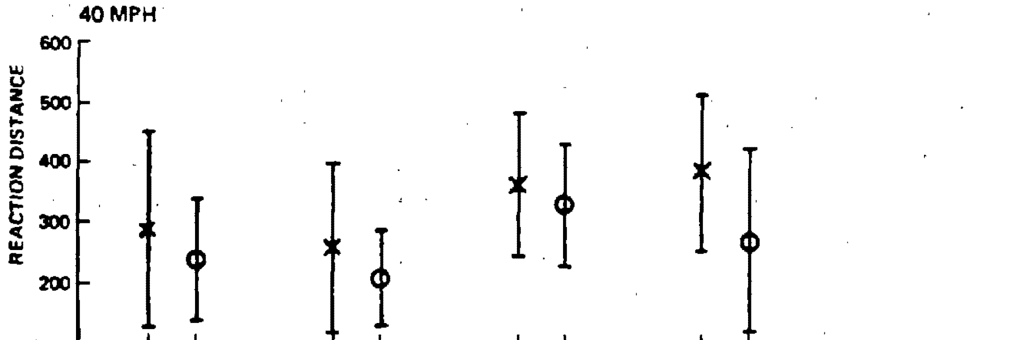
COMPARISON: Flashers On vs. Flashers Off

30 MPH




| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
|---|---|---|---|---|---|---|---|---|
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 399.6 | 278.4 | 301.7 | 210.3 | 497.5 | 526.3 | 337.4 | 325.9 | MEAN |
| 262.4 | 85.7 | 142.4 | 77.8 | 240.9 | 427.0 | 125.4 | 224.0 | S.D. |
| 2.052 | | 4.421 | | .043 | | .037 | | F |
| NS | | .05 | | NS | | NS | | SIGNIFICANCE |

40 MPH




| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
|---|---|---|---|---|---|---|---|---|
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 285.3 | 244.7 | 253.8 | 203.4 | 366.7 | 334.3 | 381.0 | 267.7 | MEAN |
| 173.3 | 106.9 | 142.7 | 88.7 | 123.5 | 105.5 | 136.5 | 157.9 | S.D. |
| 1.145 | | 2.426 | | .256 | | 3.835 | | F |
| NS | | NS | | NS | | NS | | SIGNIFICANCE |

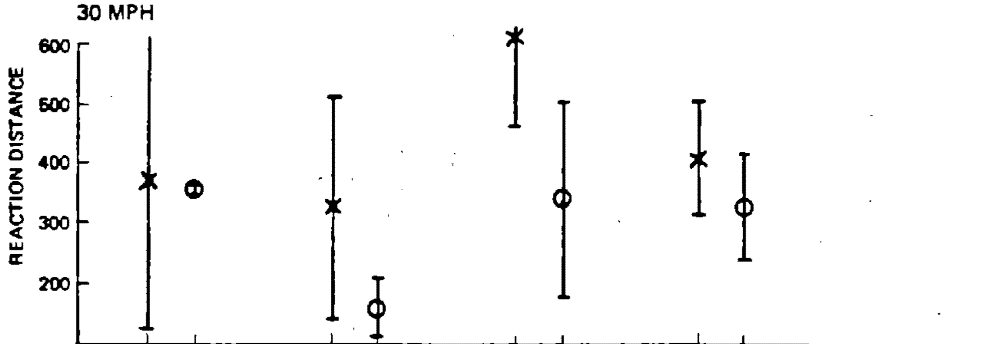
Figure 12. Reaction Distance Plots: Day

**MEASURE:** Reaction Distance

**CONDITION:** Night: Car and Truck

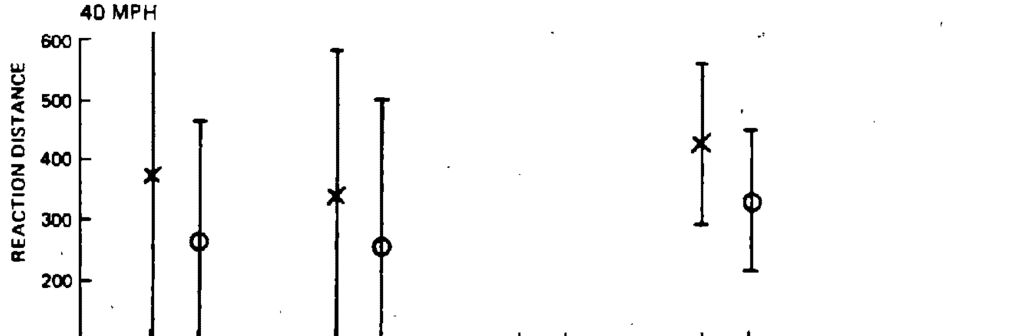
**COMPARISON:** Flashers On vs. Flashers Off

30 MPH




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 370.0 | 358.9 | 327.2 | 164.6 | 610.3 | 344.5 | 403.7 | 331.6 | MEAN |
| 257.0 | 4.2 | 191.0 | 51.8 | 159.8 | 173.0 | 98.8 | 95.7 | S.D. |
| .005 | | 2.021 | | 4.299 | | 1.778 | | F |
| NS | | NS | | NS | | NS | | SIGNIFICANCE |

40 MPH




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 373.6 | 274.2 | 338.4 | 257.6 | | | 434.1 | 328.6 | MEAN |
| 378.4 | 208.9 | 253.5 | 267.5 | | | 139.0 | 120.9 | S.D. |
| .785 | | .619 | | | | 1.172 | | F |
| NS | | NS | | | | NS | | SIGNIFICANCE |

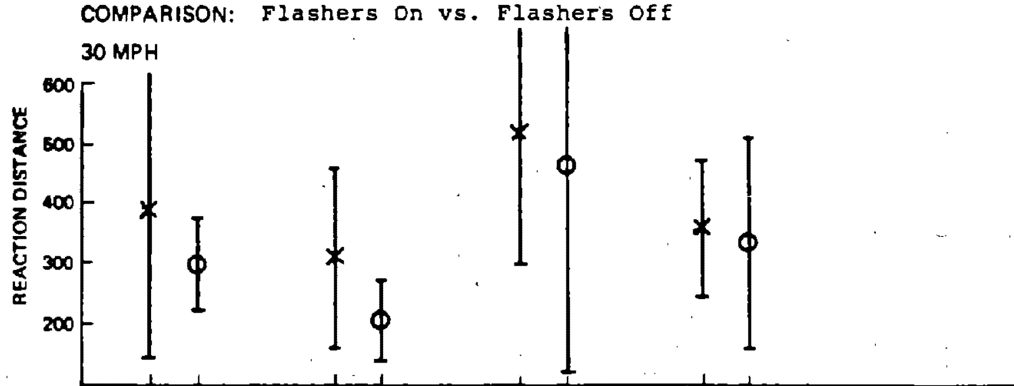
Figure 13. Reaction Distance Plots: Night

**MEASURE:** Reaction Distance

**CONDITION:** Day and Night: Car and Truck

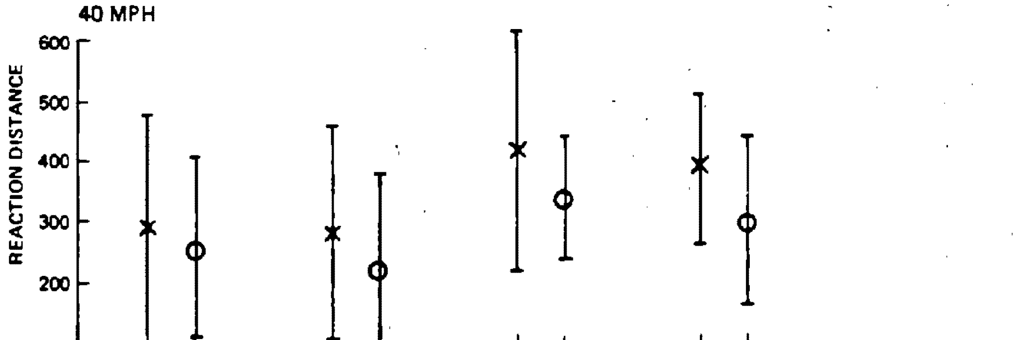
**COMPARISON:** Flashers On vs. Flashers Off

30 MPH




| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
|---|---|---|---|---|---|---|---|---|
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 391.1 | 297.0 | 308.1 | 201.2 | 515.3 | 460.2 | 350.2 | 328.3 | MEAN |
| 259.0 | 82.2 | 153.9 | 74.1 | 230.2 | 356.1 | 122.1 | 177.9 | S.D. |
| 1.662 | | 6.653 | | .267 | | .255 | | F |
| NS | | .05 | | NS | | NS | | SIGNIFICANCE |

40 MPH




| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
|---|---|---|---|---|---|---|---|---|
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 293.2 | 257.7 | 279.8 | 221.9 | 407.1 | 334.3 | 388.1 | 290.9 | MEAN |
| 198.8 | 158.3 | 184.7 | 170.4 | 204.0 | 105.5 | 133.1 | 144.9 | S.D. |
| 1.041 | | 2.128 | | .785 | | 4.212 | | F |
| NS | | NS | | NS | | .05 | | SIGNIFICANCE |

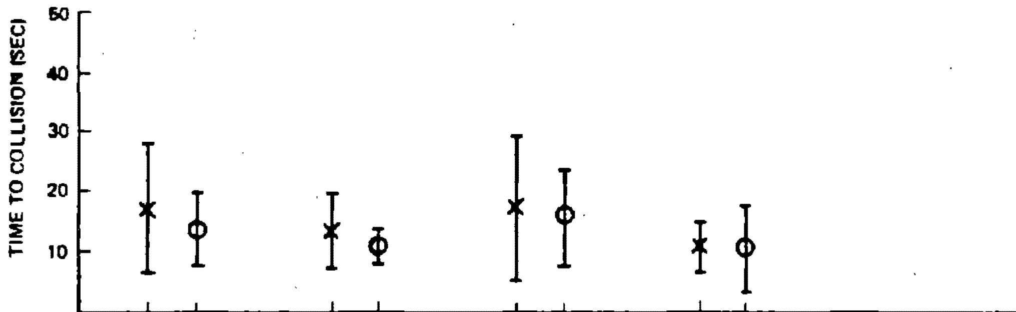
Figure 14. Reaction Distance Plots: Day and Night

**MEASURE:** Time to Collision

**CONDITION:** Day: Car and Truck

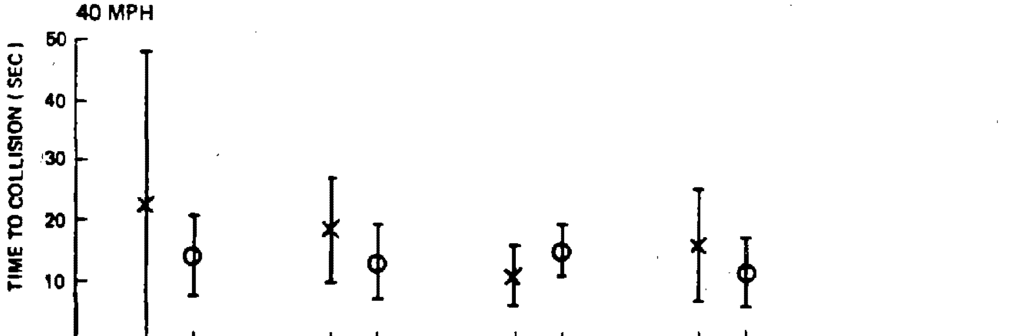
**COMPARISON:** Flashers On vs. Flashers Off

30 MPH




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 17.1 | 13.3 | 13.6 | 10.5 | 17.6 | 15.8 | 11.3 | 10.5 | MEAN |
| 11.3 | 6.3 | 6.2 | 3.1 | 12.3 | 8.8 | 4.5 | 7.7 | S.D. |
| 1.049 | | 2.705 | | .123 | | .173 | | F |
| NS | | NS | | NS | | NS | | SIGNIFICANCE |

40 MPH




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 22.6 | 14.3 | 18.4 | 13.0 | 10.8 | 14.7 | 16.0 | 11.3 | MEAN |
| 26.4 | 7.1 | 9.1 | 6.6 | 5.2 | 4.6 | 9.8 | 6.2 | S.D. |
| 2.238 | | 6.100 | | 1.984 | | 2.206 | | F |
| NS | | .05 | | NS | | NS | | SIGNIFICANCE |

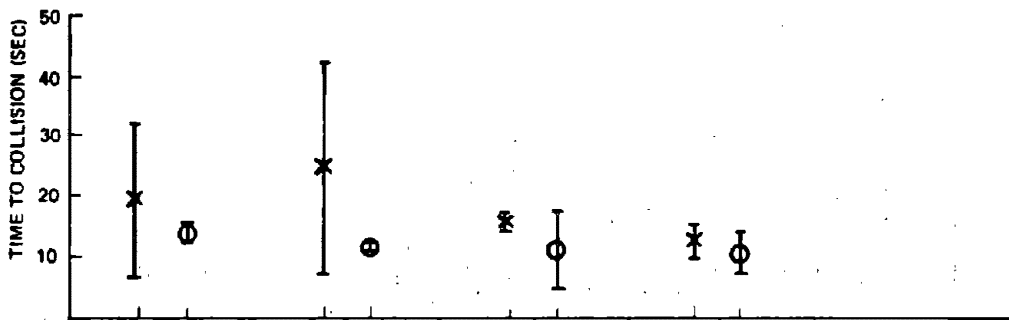
Figure 15. Time to Collision Plots: Day

**MEASURE:** Time to Collision

**CONDITION:** Night: Car and Truck

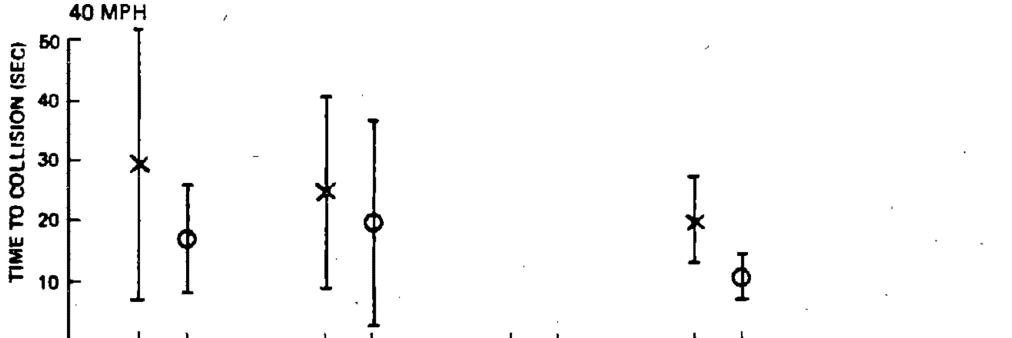
**COMPARISON:** Flashers On vs. Flashers Off

30 MPH




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 19.5 | 13.7 | 24.7 | 12.1 | 15.7 | 11.1 | 12.5 | 10.2 | MEAN |
| 13.3 | 2.0 | 18.1 | .8 | 2.0 | 7.1 | 2.9 | 3.9 | S.D. |
| .542 | | 1.368 | | 1.182 | | 1.417 | | F |
| NS | | NS | | NS | | NS | | SIGNIFICANCE |

40 MPH




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 29.3 | 17.1 | 25.2 | 19.9 | | | 19.2 | 11.2 | MEAN |
| 23.0 | 9.3 | 16.6 | 17.5 | | | 7.4 | 4.0 | S.D. |
| 3.810 | | .622 | | | | 4.836 | | F |
| NS | | NS | | | | NS | | SIGNIFICANCE |

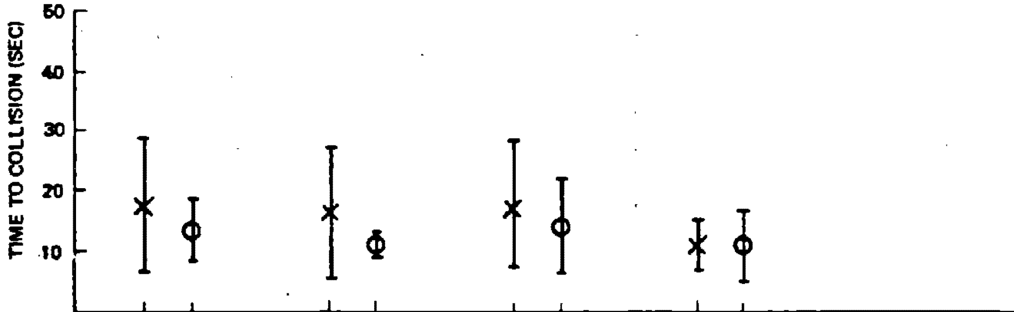
Figure 16. Time to Collision Plots: Night

**MEASURE:** Time to Collision

**CONDITION:** Day and Night: Car and Truck

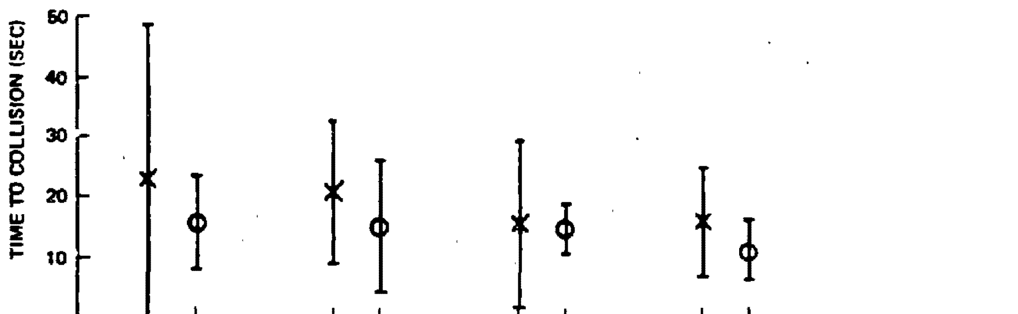
**COMPARISON:** Flashers On vs. Flashers Off

30 MPH




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 17.8 | 13.4 | 16.4 | 10.8 | 17.3 | 14.1 | 11.6 | 10.4 | MEAN |
| 11.8 | 5.5 | 11.3 | 2.8 | 11.2 | 8.2 | 4.2 | 6.3 | S.D. |
| 1.702 | | 3.488 | | .691 | | .625 | | F |
| NS | | NS | | NS | | NS | | SIGNIFICANCE |

40 MPH




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ON | OFF | ON | OFF | ON | OFF | ON | OFF | FLASHERS |
| STEEP | | SLIGHT | | STEEP | | SLIGHT | | GRADE |
| TWO-LANE | | | | FOUR-LANE | | | | LANES |
| 23.2 | 15.6 | 20.5 | 15.2 | 16.1 | 14.7 | 16.5 | 11.2 | MEAN |
| 26.1 | 8.1 | 12.2 | 11.6 | 14.6 | 4.6 | 9.4 | 5.3 | S.D. |
| 3.356 | | 3.905 | | .071 | | 4.484 | | F |
| NS | | NS | | NS | | .05 | | SIGNIFICANCE |

Figure 17. Time to Collision Plots: Day and Night

## Measure of Effectiveness: Time to Collision

Figures 15 through 17 graphically depict the time to collision data in a format like that used to present the preceding reaction distance data. The time to collision measure is the computed amount of time to the theoretical collision of the test vehicle and the overtaking vehicle if neither vehicle changed speed. The time is computed from the initial reaction point. Figure 15 shows the daylight condition data for cars and trucks combined. Seven of the eight test situations show an increase in time to collision when flashers were displayed. As was the case with reaction distance, there was also an increase in the standard deviations, especially at the two-lane sites. Under the night conditions, Figure 16, the use of flashers increased time to collision in all seven test situations for which data were available. The day and night, car and truck condition resulted in an increased time to collision in all eight test situations. In all but one situation (the four-lane slight grade site with a 30 mph [48.3 kph] test vehicle) the use of flashers also increased the variance (Figure 17).

## Effect of Four-Way Flashers on Passing Behavior

Two of the research sites had two-lane, two-way traffic flows. At these sites, drivers who came upon the slow-moving test vehicle had to decide whether to pass the test vehicle or to slow down and follow it. At both sites, passing was permitted throughout the length of the test array. The primary factor influencing drivers' decisions was the presence or absence of a clear passing opportunity. At these sites, passing behavior was coded as was a measure of passing opportunity. Passing behavior was categorized into three situations: Pass, No Pass, and Attempted but Interrupted Pass (or Aborted Pass). The last behaviors included those instances where a driver started to pass (front left wheel crossed over the center line) but did not pass. The passing opportunity coding represented a subjective judgment. The coders were trained in the specifics of the judgments and inner-rater reliability was high (above 90%). The opportunity categories were Positive, Negative, and Intermediate:

Positive: No approaching traffic; vehicle could easily pass.

Negative: Approaching traffic; either amount or position of oncoming vehicles made passing impossible.

Intermediate: Some approaching traffic; opportunity depended on type of vehicle, approach speed of oncoming vehicles, etc.

Over the two sites, 863 vehicles were charted as they approached the test vehicles. The majority (74%) of the interactions fell into two of the nine possible combinations of passing opportunity and passing behavior. Vehicles either had an open passing opportunity and passed (39%), or they had no opportunity and they did not pass (35%).

Most drivers passed when there was a clear opportunity, and did not pass when there was no opportunity. The other categories of passing opportunity versus passing behavior were examined to see if passing behavior was affected by flasher usage, since the effect of flashers might be of more consequence in those cases where the opportunity was not clear. Examining those instances of intermediate opportunity, Figure 18, an interesting point can be raised. When passing opportunity is marginal, flasher usage is associated with less passing. The category of aborted passes is larger when flashers are not used. If the finding is representative of general driving behavior, it suggests that the flashers are exerting their intended cautionary effect.

Table 31 presents a complete matrix of passing opportunity and passing behavior. In the flashers-on condition, more drivers did not pass when there was positive opportunity (8%), than when the flashers were off and there was positive opportunity (2%).

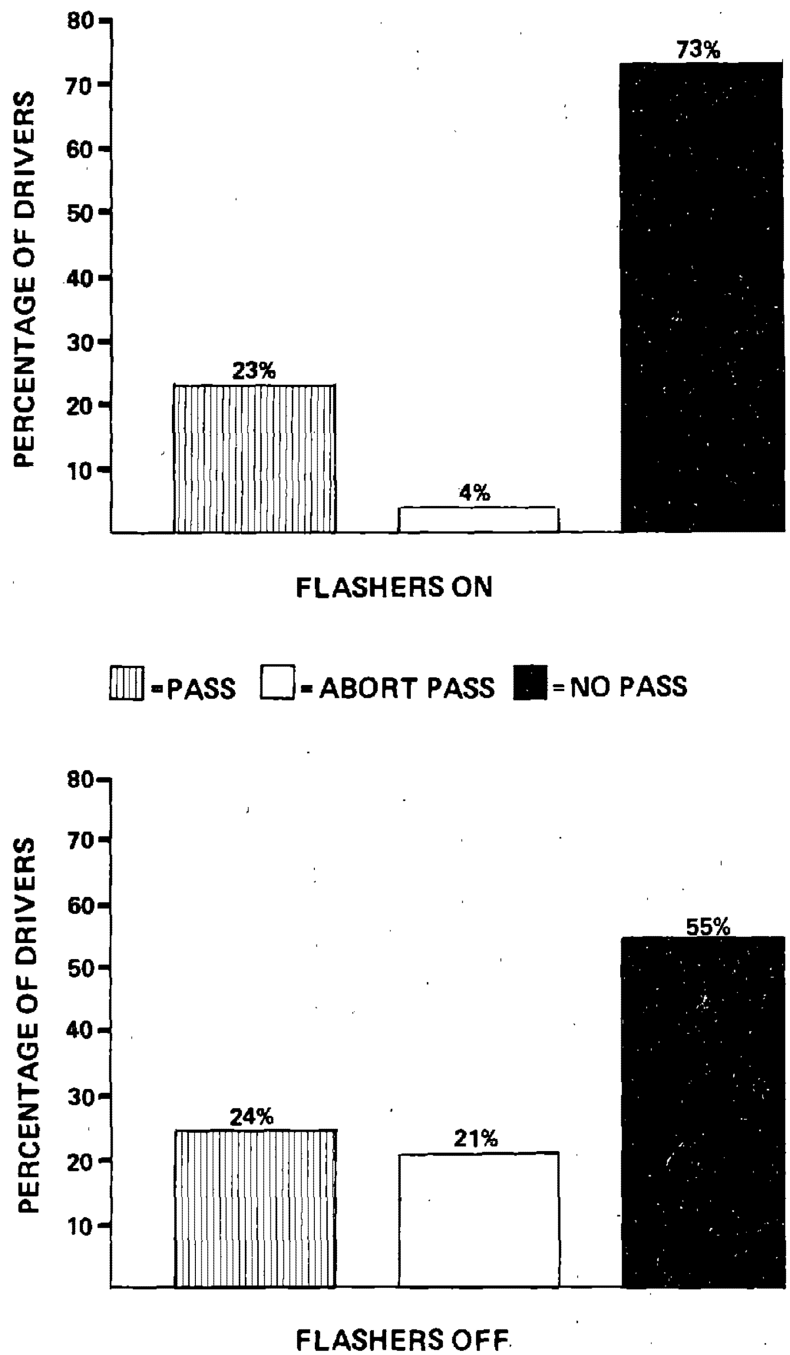



Figure 18. Passing behavior with intermediate passing opportunity on two-lane sites.

TABLE 31.

Passing Behavior Versus Passing Opportunity on Two-Lane Sites

### FLASHERS ON

PASSING OPPORTUNITY

| PASSING BEHAVIOR | POSITIVE | INTERMEDIATE | NEGATIVE | TOTAL |
|---|---|---|---|---|
| PASS | 40% | 3% | 0% | 43% |
| ABORT PASS | 1% | 1% | 3% | 5% |
| NO PASS | 8% | 11% | 33% | 52% |
| TOTAL | 49% | 15% | 36% | 100% |

### FLASHERS OFF

PASSING OPPORTUNITY

| PASSING BEHAVIOR | POSITIVE | INTERMEDIATE | NEGATIVE | TOTAL |
|---|---|---|---|---|
| PASS | 34% | 5% | 0% | 39% |
| ABORT PASS | 0% | 4% | 2% | 6% |
| NO PASS | 2% | 10% | 43% | 55% |
| TOTAL | 36% | 19% | 45% | 100% |

## Coasting Deceleration Rates

A small-scale field study was undertaken to determine the deceleration rates associated with various driving behaviors. Since brake light applications were very rarely observed, it was apparant that most drivers responded to the slow-moving vehicle by lifting off the accelerator to some degree. The coasting study was conducted to determine the deceleration rates produced by lifting off the accelerator in various ways. Since the rate of deceleration is affected by the level of incline or slope, it was necessary to measure deceleration at each of the four sites.

Three vehicles were used to determine the deceleration rates: an eight-cylinder, standard size vehicle with automatic transmission; a four-cylinder compact with automatic transmission and a four-cylinder compact with standard transmission. The test vehicles were driven into the test sites at 50 mph (80.5 kph); at a predetermined point, the driver performed one of three test procedures:

1. Lift completely off the accelerator

2. Lift completely off the accelerator for 2 seconds and return to the original throttle position

3. Lift the accelerator halfway from the position needed to maintain 50 mph (80.5 kph) on the upgrade.

An observer in the vehicle recorded the time required to pass between 300-foot (90-m) intervals marked on the shoulder of the road. Sufficient runs (6 to 8) were made to produce stable times. The high and low values were discarded and the interval times were used to compute deceleration rates.

The initial deceleration rates found at each site are shown in the top half of Table 32. The bottom half of that table shows the median deceleration rates recorded for overtaking vehicles for the 30 and 40 mph (48.3 and 64.4 kph) test vehicles, under both the flashers-on and the flashers-off conditions. At the two-lane sites, under the 30 mph, flashers-on condition the overt driver response appears to produce deceleration rates about the same as those obtained from procedure 1, lifting completely off the accelerator. However, in the 40 mph, flashers-on condition, decelerations were similar to those measured in procedure 2. Finally, decelerations were larger for the 30 mph, flashers-off condition than measured under any of the procedures, again indicating the benefit of flashers. For the four-lane sites, the deceleration rates found in the slow-moving vehicle study are more like those found in procedure 3, lifting halfway off the accelerator. Since the rate of deceleration depends on the vehicle mix (weight and type of transmission), a precise correspondence between the flasher test decelerations and the coasting study data was not expected. However, the results do provide some insights into the nature of the overtaking drivers' response to a slow-moving vehicle.

TABLE 32.

COMPARISON OF COASTING TEST DATA
AND MEDIAN DECELERATION RATES

| PROCEDURE \ SITUATION | STEEP | | SLIGHT | |
|---|---|---|---|---|
| | 4-LANE | 2-LANE | 4-LANE | 2-LANE |
| **COASTING TEST: DRIVER BEHAVIOR** | | | | |
| (1) LIFT OFF ACCELERATOR, COMPLETELY | 2.6 | 2.0 | 1.4 | 1.6 |
| (2) LIFT OFF ACCELERATOR FOR 2 SEC. | 1.3 | 1.7 | .7 | 1.1 |
| (3) LIFT OFF ACCELERATOR, HALFWAY | .8 | 1.1 | .7 | .9 |
| **SLOW-MOVING VEHICLE CONDITION: MEDIAN DECELERATION** | | | | |
| FLASHERS ON, 30 mph | .8* | 1.7** | 1.1* | 1.7** |
| FLASHERS ON, 40 mph | .8 | 1.3 | .9 | 1.1 |
| FLASHERS OFF, 30 mph | .9 | 2.3 | .8 | 1.9 |
| FLASHERS OFF, 40 mph | .7 | 1.2 | .8 | 1.5 |

*All four-lane deceleration rates are for passing vehicles.

**All two-lane deceleration rates are for nonpassing vehicles.

## Summary

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. For example, an increase in initial reaction distance or an increase in time to collision indicates that overtaking vehicles are farther from the slow-moving vehicle when the overtaking driver begins slowing down and that the drivers are reacting more cautiously.

Four of the eight 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 overtaking vehicle drivers responded to the slow-moving vehicle with flashers at a greater distance than they do to a slow-moving vehicle without flashers.

- Time to Collision (TTC): An increase in the time to collision measure indicated that approaching vehicle drivers 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 approaching vehicles to slow down farther from the slow-moving vehicle.

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

The remaining four dependent measures have revealed less clear interpretations as measures of effectiveness. A decrease in speed at the initial reaction point (IRP) might indicate that overtaking vehicle drivers who were aware of the relative speed difference between their vehicle and the slow-moving vehicle merely maintained speed right up to the point of initial reaction. The remaining three dependent measures, maximum deceleration, speed at maximum deceleration (SMD), and passer speed at lane change (PSLC), can be interpreted in a similar fashion.

Throughout the preceding sections, the persistence of the effects of flashers were evident. The results were often insignificant in a statistical sense, but the changes in each measure were remarkably consistent across a variety of test conditions. Tables 33 through 35 summarize the "safety implications" of each of these measures of effectiveness. The direction of change produced by flasher condition is indicated by either a plus or a minus sign. If the flashers produced a change that indicates a positive safety improvement, a plus sign is shown. Only the dependent measures with unambiguous interpretations in terms of safety benefit are included.

Table 33 summarizes the research results relative to the safety implications of flasher use during daylight conditions for cars, trucks, and cars and trucks combined. The effects are especially consistent for the two-lane sites with the 30 mph (48.3 kph) slow-moving vehicle, with an improvement indicated for all measures. The two-lane sites with the 40 mph (64.4 kph)

TABLE 33.

Measures of Effectiveness: Safety Implications

**Condition:** Day: Car, Truck, Car and Truck

**Comparions:** Flashers On vs. Flashers Off

| Condition | Dependent Measure \ Situations | 30 mph | | | | 40 mph | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2 Lane | | 4 Lane | | 2 Lane | | 4 Lane | |
| | | Steep | Slight | Steep | Slight | Steep | Slight | Steep | Slight |
| Car | Initial Reaction Distance (ft) | + | + | – | + | + | – | + | + |
| | Time to Collision at IRP (mph) | + | + | + | + | + | + | – | + |
| | Distance at Max. Dec. (ft) | + | + | – | – | + | + | + | + |
| | Passer, Distance at Lane Change | + | ● | + | + | + | – | + | + |
| Truck | Initial Reaction Distance (ft) | + | + | ● | ● | + | + | – | + |
| | Time to Collision at IRP (sec) | + | + | ● | ● | + | + | – | – |
| | Distance at Max. Dec. (ft) | + | + | ● | ● | + | + | – | + |
| | Passer, Distance at Lane Change (ft) | ● | ● | + | + | – | ● | + | + |
| Both | Initial Reaction Distance (ft) | + | + | – | + | + | + | + | + |
| | Time to Collision at IRP (sec) | + | + | + | + | + | + | – | + |
| | Distance at Max. Dec. (ft) | + | + | – | – | + | + | + | + |
| | Passer, Distance at Lane Change (ft) | + | ● | + | + | + | – | + | + |

\+ indicates an improvement in safety
– indicates a reduction in safety
● indicates no data

TABLE 34.

Measures of Effectiveness: Safety Implications of Flashers, Night Conditions

**Condition:** Night: Car, Truck, Car and Truck

**Comparions:** Flashers On vs. Flashers Off

| Condition | Dependent Measure \ Situations | 30 mph | | | | 40 mph | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2 Lane | | 4 Lane | | 2 Lane | | 4 Lane | |
| | | Steep | Slight | Steep | Slight | Steep | Slight | Steep | Slight |
| Car | Initial Reaction Distance (ft) | ● | ● | ● | + | + | + | ● | ● |
| | Time to Collision at IRP (mph) | ● | ● | ● | + | + | – | ● | ● |
| | Distance at Max. Dec. (ft) | ● | ● | ● | + | + | + | ● | ● |
| | Passer, Distance at Lane Change | + | ● | + | + | ● | ● | ● | + |
| Truck | Initial Reaction Distance (ft) | – | + | ● | ● | + | + | ● | ● |
| | Time to Collision at IRP (sec) | + | + | ● | ● | + | + | ● | ● |
| | Distance at Max. Dec. (ft) | + | + | ● | ● | + | + | ● | ● |
| | Passer, Distance at Lane Change (ft) | ● | ● | ● | ● | ● | ● | ● | + |
| Both | Initial Reaction Distance (ft) | + | + | + | + | + | + | ● | + |
| | Time to Collision at IRP (sec) | + | + | + | + | + | + | ● | + |
| | Distance at Max. Dec. (ft) | + | + | + | + | + | + | ● | + |
| | Passer, Distance at Lane Change (ft) | + | ● | + | + | – | | | + |

+ indicates an improvement in safety
– indicates a reduction in safety
● indicates no data

TABLE 35.

Measures of Effectiveness: Safety Implications of Flashers, Day and Night Combined

**Condition:** Day or Night: Car and Truck Combined

**Comparions:** Flashers On vs. Flashers Off

| Condition | Dependent Measure \ Situations | 30 mph | | | | 40 mph | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2 Lane | | 4 Lane | | 2 Lane | | 4 Lane | |
| | | Steep | Slight | Steep | Slight | Steep | Slight | Steep | Slight |
| Both Car & Truck | Initial Reaction Distance (ft) | + | + | + | + | + | + | + | + |
| | Time to Collision at IRP (sec) | + | + | + | + | + | + | + | + |
| | Distance at Max. Dec. (ft) | + | + | + | + | + | + | + | + |
| | Passer, Distance at Lane Change (ft) | + | + | + | + | + | + | + | + |

+ indicates an improvement in safety
– indicates a reduction in safety

test vehicle were the next most consistent, followed by the four-lane sites with the 30 mph (48.3 kph) test vehicle. The four-lane steep site showed the smallest amount of improvement, especially with the test truck at 40 mph (64.4 kph).

Table 34 summarizes the research results relative to the safety implications of flasher use after dark. The improvement is somewhat more consistent than during daylight conditions. For the slow-moving car, only the TTC measure for the two-lane slight site with a 40 mph (64.4 kph) test vehicle failed to show a safety benefit. For the 30 mph (48.3 kph) slow-moving truck, the IRD at the two-lane steep site did not show a safety benefit. When both test vehicles are considered together, the only measure that did not show an improvement was the PDLC at the two-lane steep site with a 40 mph (64.4 kph) slow-moving vehicle.

Table 35 combines the day and night data for the slow-moving car and truck. All four measures of effectiveness indicate an improvement in safety across all eight test conditions. Although the effects are not always statistically significant, the direction of improvement is completely consistent across all conditions.

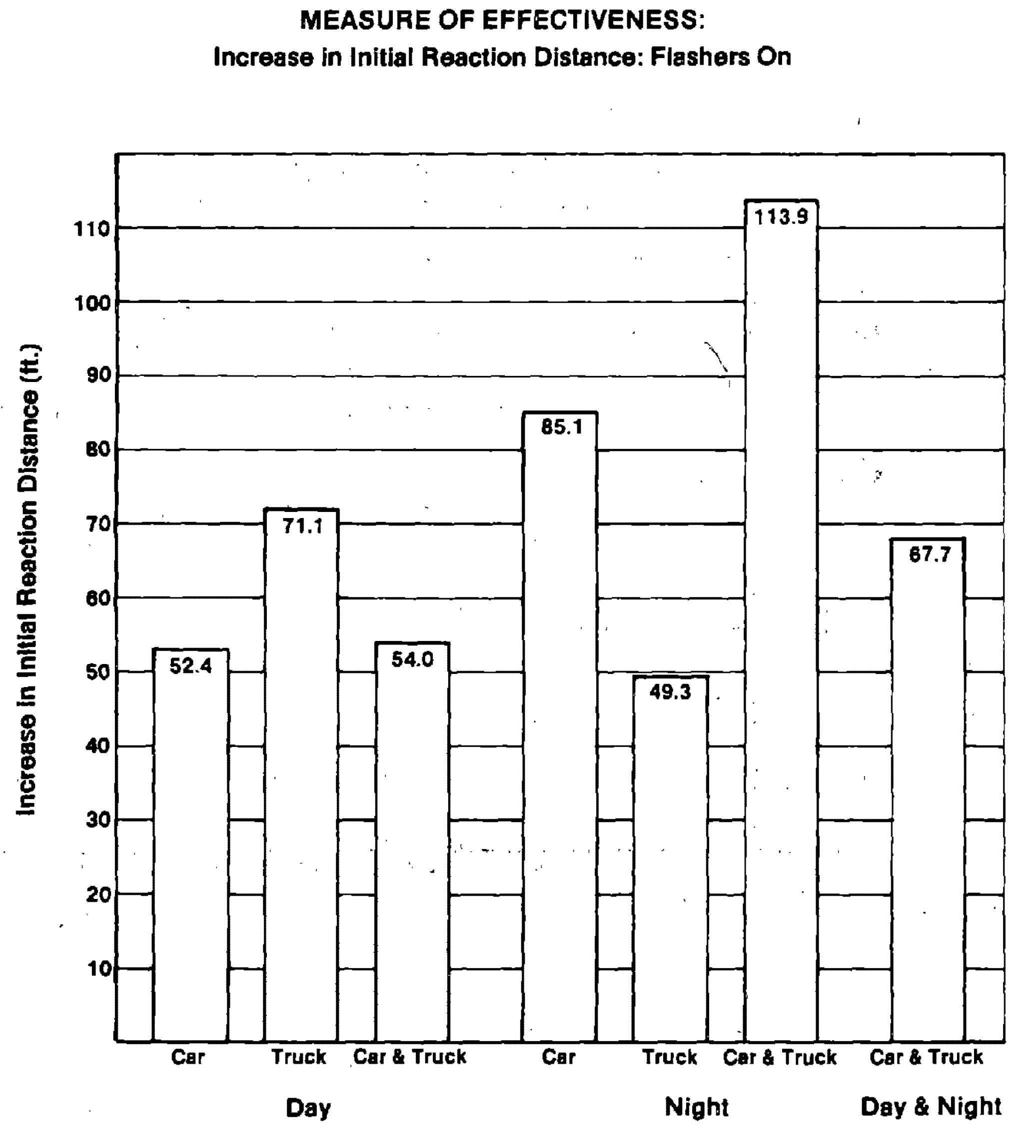
The amount of change in each MOE is shown in Figures 19 through 22. The values shown are the averages across all eight test situations. The "car" and "truck" values are the means for the car and truck conditions, respectively. Values shown in the "car and truck" column are the MOE values for the slow-moving car and truck combined and then averaged across all test situations. Therefore, these combined car and truck values contain data from some test situations which were not in the separate car or separate truck values.

Figure 19 shows the increase in reaction distance produced by the flashers-on condition. In daylight the flashers on the slow-moving car increased reaction distance 52.4 feet (15.7 m). On the slow-moving truck the flashers were somewhat more effective. At night the flashers increased reaction distance 85.1 feet (25.5 m) for the car and 49.3 feet (14.8 m) for the truck. The average increase in reaction distance across all situations for the test car and the test truck, day and night combined, was 67.7 feet (20.3 m).

Figure 20 shows the increase in time to collision produced by the flashers-on condition. The increase was always greater at night, for the car, the truck, and the car and truck combined groups, than it was during daylight. The average increase across all situations for the test car and the test truck, day and night combined, was 4.3 seconds.

Figure 21 shows the increase in distance at maximum deceleration resulting from the flashers-on condition. The profiles are similar to those for increase in reaction distance. The increases are similar in magnitude to those for reaction distance with smaller differences occurring between car and truck values and more consistency occurring in the day/night values.

Figure 22 shows the increase in passer distance at lane change produced by the flashers-on condition. Approaching vehicles pull out to pass farther away from the slow-moving vehicle when the flashers are displayed. Unfortunately, there was less passing at night, so the sample size for the car and the truck night tests was too small ($N < 10$). However, the car and truck combined increase was 30.6 feet (9.2 m) in daylight and 94.8 feet (28.4 m) at night. The combined day and night, car and truck, average was 55.7 feet (16.7 m). Overtaking vehicles initiated their pass approximately three car lengths earlier when the flashers were displayed.




1 foot = .3 m

Figure 19. Measure of effectiveness: Increase in initial reaction distance: Flashers on

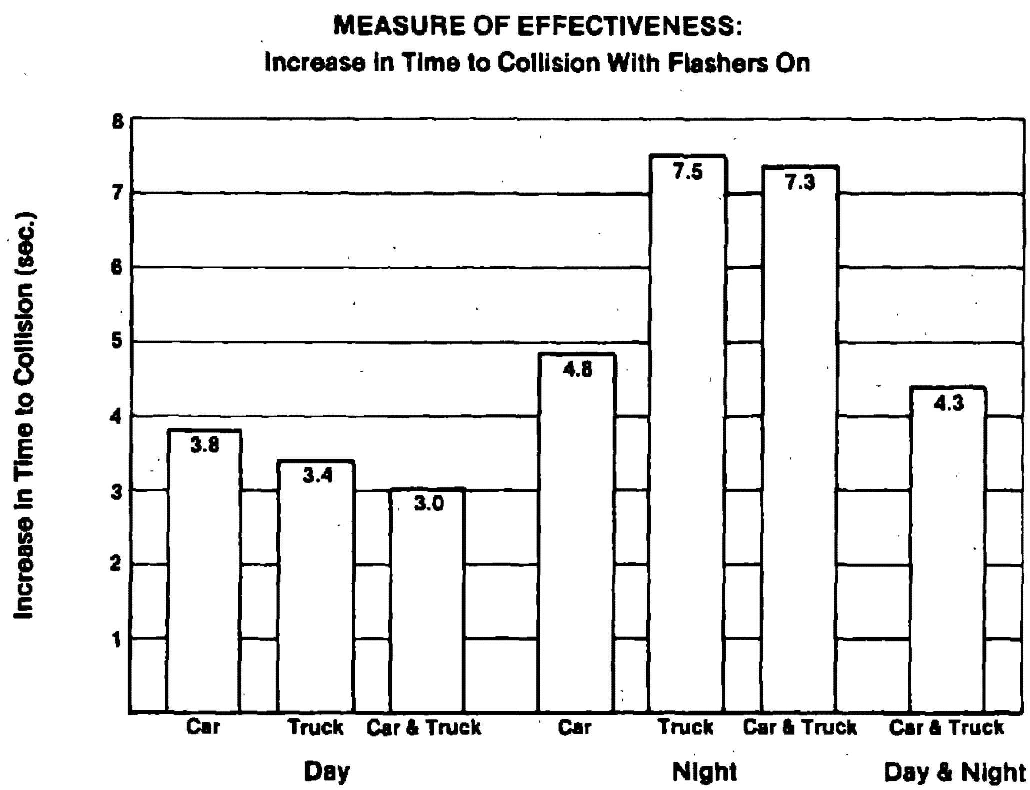
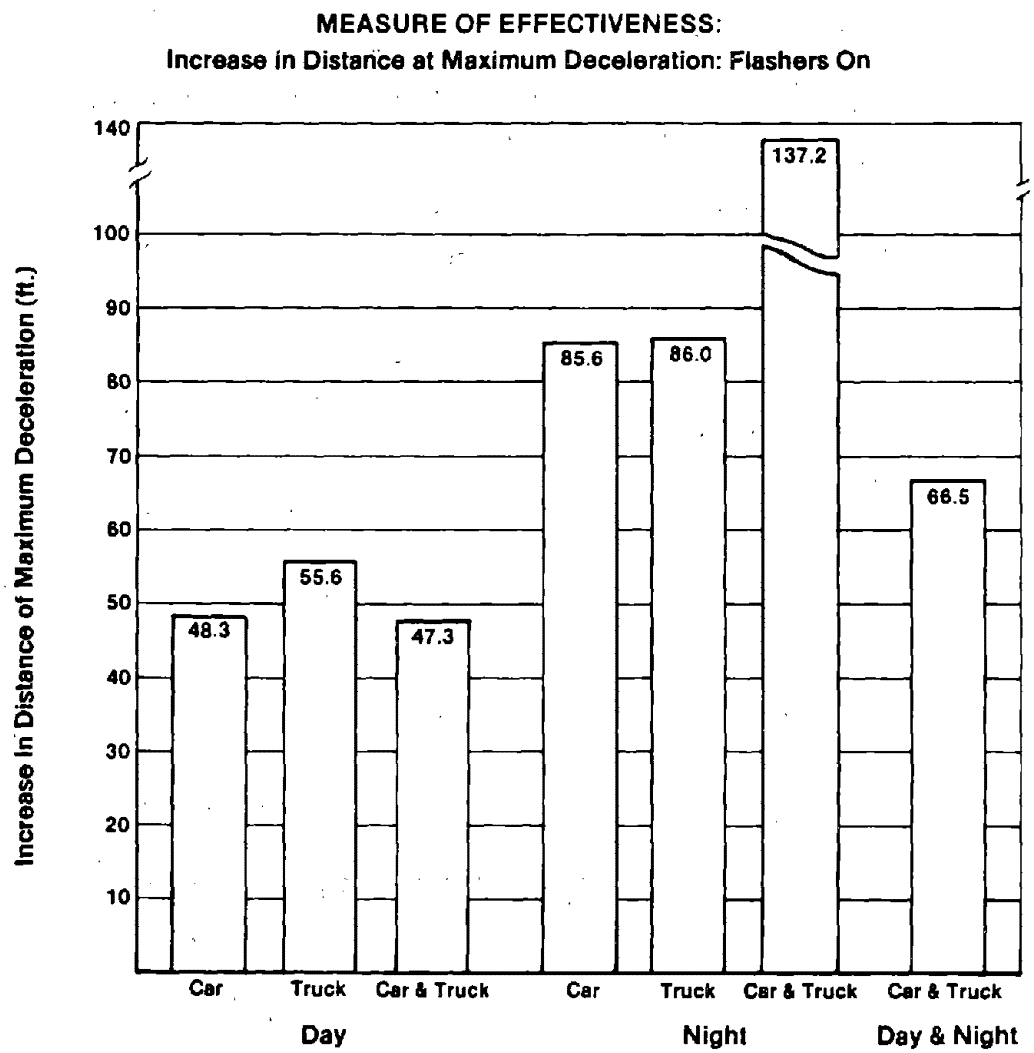
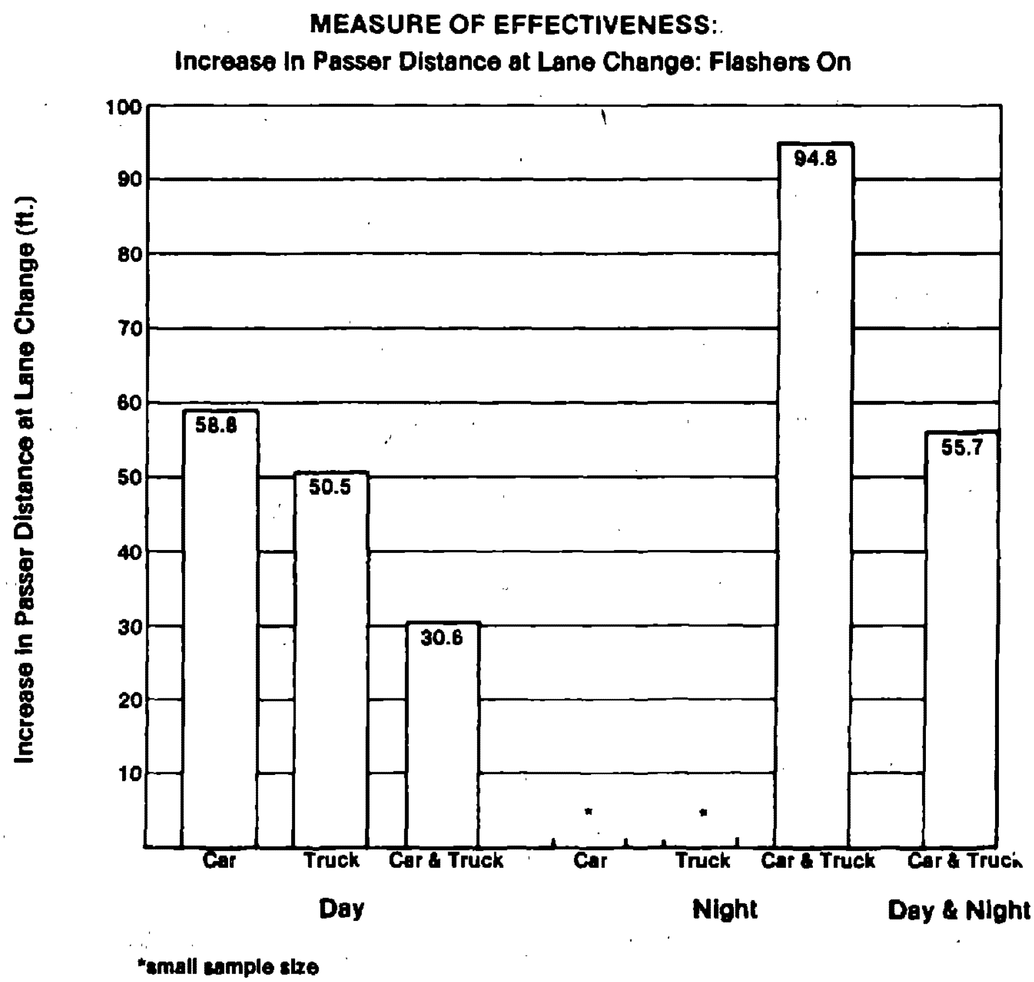



Figure 20. Measure of effectiveness: Increase in time to collision: Flashers on




1 foot = .3 m

Figure 21 Measure of effectiveness: Increase in distance at maximum deceleration: Flashers on




1 foot = .3 m

Figure 22. Measure of effectiveness: Increase in passer distance at lane change: Flashers on

# IV. CONCLUSIONS AND GUIDELINES

## 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 36 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 36.

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 | + | + | ● | + |

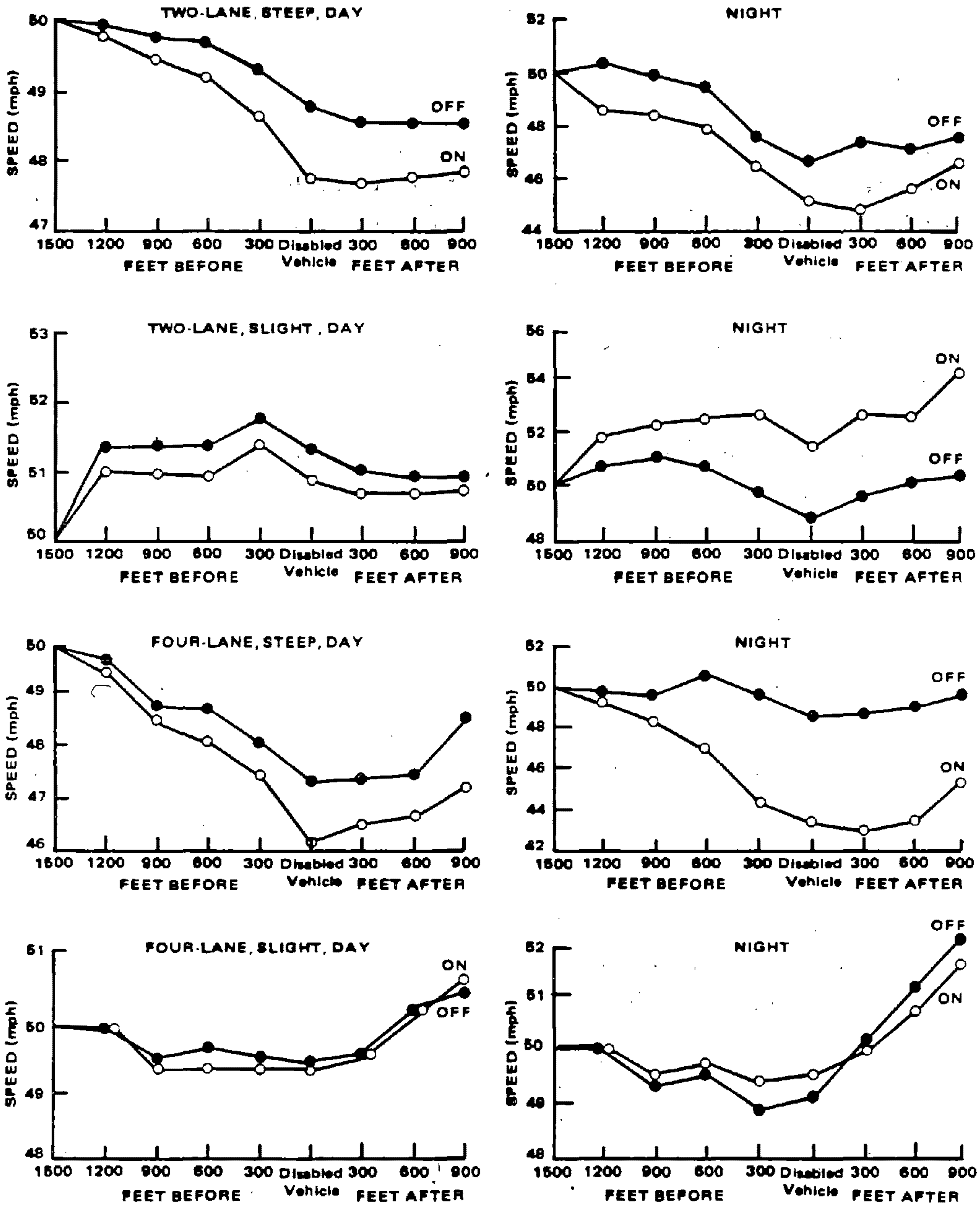
**Legend:**
+ = Positive effect on safety
— = Negative effect on safety
O = No effect
● = No data

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 Lane 1 mean speed reductions. 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 traffic stream as it approaches and passes the disabled vehicle. Figure 23 shows the speed profiles for each of the eight experimental situations. 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 grades and the slight grades 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 23. 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 37 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 23. 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 37
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.

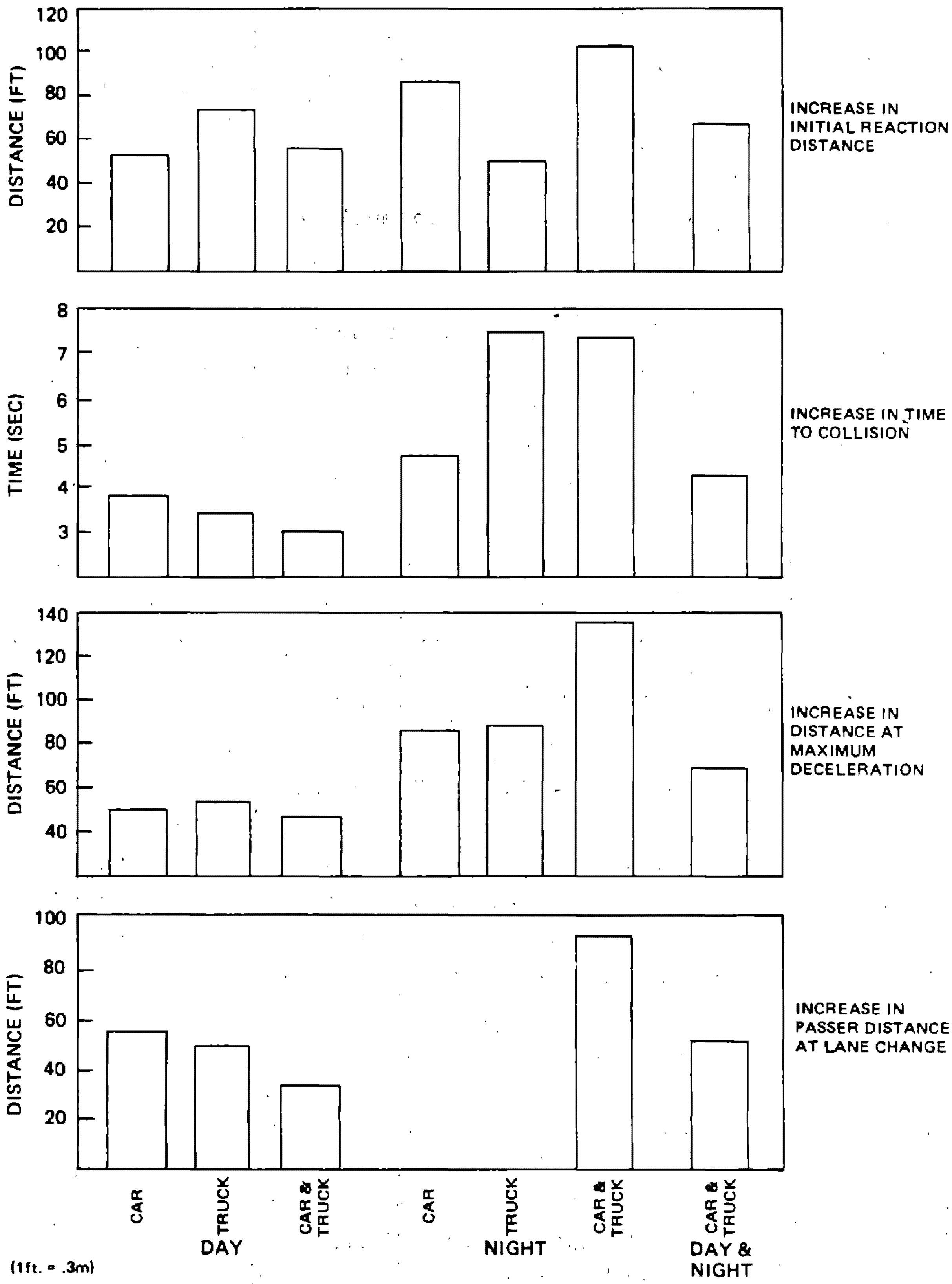



Figure 23. Effectiveness of four-way flashers: Increase in MOEs.

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 started to pass, with the left front wheel crossing the center line, but subsequently did not pass the slow-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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