DEVELOPMENT AND TESTING OF TECHNIQUES FOR INCREASING THE CONSPICUITY OF MOTORCYCLES AND MOTORCYCLE DRIVERS

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16. Abstract

This project was initiated to determine whether it might be possible to reduce the incidence of multi-vehicle motorcycle crashes by improving the conspicuity of the motorcycle-driver unit. Specifically, the following tasks were carried out:

1. A review of motorcycle accident data.
2. Development of potential conspicuity treatments.
3. Field evaluation of a selected sample of these treatments.
4. Determination of cost benefits.

A crash data analysis carried out by HSRI, together with several other published studies, makes it clear that motorcycles are overinvolved (relative to cars and trucks) in accidents in which the other vehicle is executing a maneuver (generally a left turn) across their path.

More than thirty conspicuity treatments were developed and demonstrated for subjective appraisal. A sample of these was selected for field evaluation.

The countermeasures were evaluated by means of a gap-acceptance procedure. The study was run in normal traffic, and measures were taken on drivers who were not aware they were involved in a study.

The results indicate that daytime conspicuity can most effectively be improved by use of fluorescent garments or steady or modulating lights. Nighttime conspicuity seems to be aided by use of retroreflective garments and running lights.

The cost-benefit analysis indicated that all of the items found to produce significant conspicuity effects are also cost-beneficial.

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TECHNICAL SUMMARY

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Motorcycles are at once a bane and a blessing. They are a fuel-stingy form of transportation and recreation for millions of Americans. They are also a relatively dangerous vehicle to ride, with thousands of persons being killed and hundreds of thousands being injured annually. As ways were sought to reduce this toll, it began to appear that a significant proportion of motorcycle-car crashes came about because of problems the car driver had in seeing and/or properly identifying motorcycles in certain types of potential conflict situations. It was thought that means for enhancing the conspicuity of motorcycles and/or motorcyclists might prove an effective accident countermeasure.

This project was initiated in 1976 by NHTSA to develop and test conspicuity treatments for both day and night use. Specifically, the following steps were undertaken:

1. A review of motorcycle accidents.
2. Development of potential conspicuity treatments.
3. Field evaluation of the effectiveness of the treatments.
4. Analysis, interpretation, and calculation of cost-effectiveness.

The accident analysis was based on a sample of about 10,000 motorcycle crashes which occurred in Texas in 1975. These were compared with a like-sized sample of car accidents from the same period. The most important finding was that certain types of pre-crash orientations are much more prevalent in motorcycle than in car crashes. The most common configuration for a motorcycle accident involves a straight traveling bike and left turning car. While a left-turn maneuver is often difficult, the overrepresentation of left-turning cars in the motorcycle accident data suggests that there is indeed a conspicuity problem.

Other points which emerged from the accident analysis were the following:

1. Persons wearing bright colored clothing seem underrepresented.
2. There is some reason to believe the conspicuity problem may not be as serious at night.

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These data are in general agreement with the results of the in-depth motorcycle accident study carried out by Hurt and his colleagues for NHTSA.

Using various lighting techniques and high-visibility materials, more than 30 conspicuity treatments were developed for both day and night use. A sample of the most promising ones was selected for evaluation.

A gap-acceptance methodology was used in the evaluation stage. To do this, instrumented motorcycles were placed in the traffic stream. The riders attempted to open a space (gap) between themselves and leading traffic large enough to tempt other vehicles waiting to cross the lane to undertake the maneuver (accept the gap). Measures were made of gap size (both time and distance), whether the gap was accepted or not, and the type of maneuver involved. The data were analyzed to determine the probability of relatively short gaps being accepted. It was anticipated that improving conspicuity should reduce the probability of very short gaps being accepted. The method worked very well.

The results of the study indicate that daytime conspicuity can be significantly improved by:

1. Causing the headlamp to modulate at a rate of about 3 hz.
2. Riding with the headlamp on.
3. Wearing high visibility (fluorescent) garments.

It was especially interesting to note that the same high-visibility materials, when attached to the bike, were not as effective.

The nighttime results were not as clear cut. However, it appears that the use of running lights and retroreflective garments may be beneficial. Again, the same retroreflective materials attached to the bike were not as effective.

Another part of the study examined lane position (right, left, or center) as a factor in gap acceptance. The probability of short gaps being accepted was lowest for the center lane position, and next lowest for the left lane position.

A test was also run to examine the effect of having a car following behind the motorcycle. The results suggest that the presence of a car close behind a motorcycle (one second headway in this case) may reduce the probability of short gaps in front of the motorcycle being accepted for one of the maneuvers studied.

Limited tests were also run with a moped, using a single treatment. While the results suggest a beneficial effect associated with the use of a fluorescent flag, the response characteristics of the automobile drivers were so much different to the mopeds than to the motorcycles that it is felt the method may not be appropriate for such slow moving vehicles.

The results of this study indicate that motorcycle conspicuity can be improved in a cost-beneficial way using any of a variety of techniques.

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This was a complex study, the smooth and successful completion of which was possible only with the cooperation of a large number of people. In particular, the authors would like to express their great appreciation to the Contract Technical Monitor, Dr. Robert Henderson, who provided valuable guidance and assistance throughout the project.

The authors would also like to express their appreciation to the young men and women who assisted in data collection. Special thanks go to Michael and Patrick Barton and Michael Gladden, who not only aided in data collection, but recruited and trained other riders and helped to maintain the bikes.

Finally, we were greatly aided by Mr. Robert Vanstrum of 3M Company, who supplied most of the materials used in the test, as well as a great deal of technical information.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Background

Motorcycles have recently enjoyed phenomenal growth both as forms of basic transportation and in recreation. Since 1961 motorcycle registrations have increased at nearly four times the rate of all other vehicles. In 1977 U.S. motorcycle registrations passed the five million mark. Also in 1977, nearly ten percent of these motorcycles were involved in accidents. These mishaps caused about 4,000 deaths and about 400,000 injuries (Carraro, 1979).

The principal safety problem with motorcycles is the vulnerability of the persons who ride them. When a motorcycle becomes involved in a crash, its occupants are about ten times more likely to suffer injury than if they were in a car (Carraro, 1979).

The engineering solutions which have helped reduce crash-related dangers in automobiles (e.g., seat belts) cannot be applied to motorcycles without significantly changing their nature. Thus, motorcycle riders will remain vulnerable. Consequently, the injury rate per crash will likely remain high for the foreseeable future.

Some trends in the motorcycle accident data suggest means to reduce the frequency of motorcycle crashes. For example, there is reason to believe that a significant number of motorcycle-car crashes are conspicuity related; i.e., car drivers, for whatever reason, often behave as though they do not see motorcycles. If motorcycles are hard to see, making them more conspicuous should reduce the incidence of such crashes.

1.2 The Present Study

The National Highway Traffic Safety Administration (NHTSA) recognized the safety potential of making motorcycles, motorcyclists, and mopeds more conspicuous. In 1976, NHTSA awarded a contract to the Highway Safety Research Institute (HSRI) of the University of Michigan to discover and test ways of making motorcycles and motorcyclists more conspicuous. Specifically, the original project aimed to complete the following six activities:

1. Examine motorcycle accident data to determine:
    - the importance of conspicuity problems, and
    - potential means for making motorcycles more conspicuous.
2. Review past studies of motorcycle conspicuity and conspicuity in general.
3. Survey relevant basic and applied research related to visual perception.
4. Recommend nighttime and daytime conspicuity treatments that might be applied to the bike and/or rider.
5. Evaluate the proposed treatments under realistic field conditions.
6. Analyze and interpret the data resulting from step 5, including consideration of costs and benefits.

In 1978, the project was expanded to cover additional conspicuity treatments, motorcycle lane positioning effects, and moped conspicuity in the field testing activities.

1.3 Previous Investigations of Motorcycle Conspicuity

Several other investigations of motorcycle conspicuity preceded this one.

Reiss and Haley (1968) first identified conspicuity as a significant problem area in motorcycle-automobile collisions. They state (pp. 2-3):

> "A large number of motorcycle-automobile collisions are related to the fact that the motorist does not see the motorcycle until too late..."

Their analysis of the potential cost-effectiveness of motorcycle countermeasures shows that those dealing with conspicuity rank third behind motorcyclist licensing and helmet use. Subsequent problem identification projects (e.g., Reiss, Berger, & Vallette, 1974) produced similar conclusions.

Woltman and Austin (1973) carried out a systematic analysis aimed at understanding the conspicuity problem. They compared the size of the surface area of motorcycles with other vehicles and pedestrians. Their analysis suggests the conspicuity problem stems from the relatively small size of motorcycles in comparison with other vehicles.

One simple way of making motorcycles more conspicuous during the day is to turn on the headlamp. In the late 1960's, many states passed "lights-on" laws, mandating the daytime use of headlights on motorcycles, and several studies tested the effect of this countermeasure. The Franklin Institute (Janoff, Cassel, Fartner, and Smierciak, 1970; Janoff & Cassel, 1971; Janoff, 1973) evaluated how effectively daytime headlight use increased motorcycle conspicuity. They examined accident data, comparing states with and without lights-on laws, and took field measurements of motorcycle conspicuity, as reported by other motorists. The results of both types of studies indicate a positive conspicuity benefit for daytime headlight use.

Subsequent analyses of accident experience in states with and without lights-on laws (Waller & Griffin, 1977), and the daytime conspicuity of a motorcycle with its headlight on (Ramsey & Brinkley, 1977, William & Hoffman, 1977) provide additional evidence that lights-on enhances conspicuity.

Turn signals might be used as running lamps to improve conspicuity as well. Some evidence, reported by Bartol et al. (1975), indicates running lights increase nighttime conspicuity. A recent test of the daytime conspicuity of running lights, by a panel of SAE experts, indicates potential benefits, but the evidence favoring this countermeasure is rather weak.

A recent study by Ramsey & Brinkley (1977) examined the conspicuity of strobe and flashing lights. The researchers found that other motorists, when stopped and asked whether they saw a motorcycle they had just passed, noticed motorcycles equipped with a medium- to high-intensity flashing light more often than motorcycles with no or low-intensity lights.

In addition to lights, other means are available to improve conspicuity. For example, Woltman & Austin (1973) suggested that fluorescent and retroreflective garments and accessories might increase motorcycle/motorcyclist conspicuity. Studies performed by Burg and Beers (1976), Williams and Hoffman (1977), and Bartol et al. (1975) demonstrated that detection and identification distances increase with special fluorescent and retroreflective paints and garments.

Kirkby and Stroud (1978) used a gap-acceptance methodology to evaluate the effectiveness of lights-on and high visibility clothing on the behavior of motorists. The study was set up on a traffic circle and data taken on videotape from a central location to measure changes in percent acceptance of different gaps between the test motorcycle and a lead car. The authors found no differences between the treated and control configurations.

Williams and Hoffman (1977) compared the conspicuity of high-visibility motorcyclist clothing, fairings, and headlights. They found, in a series of laboratory studies using slides of road scenes with or without a motorcycle present, that headlamp use, a fluorescent jacket, and fairing increased motorcycle detectability over an untreated control.

In sum, data from a number of studies, using a variety of techniques, suggest several means for improving motorcycle conspicuity. These are:

- daytime use of headlights
- running lights

- flashing lights
- fluorescent garments or paints
- retroreflective devices and garments
- fairings

Only the daytime use of headlights can be said to have been extensively tested under real-world conditions. One of the problems with the other studies stems from an apparent assumption that poor conspicuity equals "failure to see." Actually the trends in the crash data which will be reviewed in the next section could be explained by failure to see and any or all of the following:

- misidentification as a low-performance vehicle
- errors in speed-spacing judgments
- deliberately perverse behavior on the part of the car driver.

It is not likely that the primary problem (if there is a primary problem) can be identified in a single study. However, the work to be described examines the problem from several points of view and offers some interesting insights regarding possible explanations.

The rest of this report is directed to a description of the methods, findings, conclusions, and recommendations of this project.

2.0 A REVIEW OF MOTORCYCLE ACCIDENT DATA

2.1 Questions to be Addressed

For operational purposes let us define the motorcycle conspicuity problem as occurring:

> ...whenever another motorist fails to see, identify, or appropriately react to a legally used motorcycle, or, in the case of colliding with a motorcycle, claims such a failure resulted in a crash.

Given this statement, the primary question which it is hoped motorcycle crash data might answer is the following:

> Do differences between patterns of motorcycle-car[1] and car-car crashes suggest other drivers sometimes fail to see or identify motorcycles?

If the crash data suggest motorcycles are difficult to see and identify, four additional questions become meaningful:

1. Do data suggest a day-night difference in motorcycle conspicuity?

This question stems from an intuitively expected difference. During the daytime, drivers look for and see other vehicles directly. But, in the nighttime, headlamps and taillights are the dominant cues for seeing and identifying other vehicles. Thus, motorcycles should be relatively more visible at night.

2. Do data suggest crash involvement varies with the conspicuity of the motorcyclist?

This question arises from the expectation that more conspicuous motorcycles should be involved in relatively fewer crashes. In searching for an answer to this question, we examined the color of clothes crash-involved motorcyclists were wearing and similar variables.

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[1] We will use the term "car" to refer to automobiles, trucks, etc., and "motorcycles" to refer to motorcycles and mopeds.

3. What are the most prevalent motorcycle-car crash configurations?

An answer to this question will aid in tracing the roots of the conspicuity problem. Finding that specific crash configurations are more prevalent in motorcycle-car than in car-car crashes might suggest angles at which motorists have difficulty in seeing motorcycles, and other driver errors motorcyclists find difficult to defend against.

4. How severe is the conspicuity problem; i.e., how many motorcycle crashes involve the conspicuity problem?

This final question provides a measure of the extent of the conspicuity problem. We need an estimate of how prevalent the problem is, at least in crashes, in order to effectively analyze the costs and benefits of potential countermeasures.

2.2 Previous Motorcycle Accident Analyses

There have been several analyses of motorcycle accidents published. These are reviewed below.

2.2.1 Analyses of U.S. Motorcycle Accidents. In the U.S., motorcycle accident analysis started in the late 1960's. The work has covered specific issues (e.g., the work of Waller and Griffin, 1977, on lights-on laws), as well as providing detailed, in-depth and broad spectrum analyses of motorcycle accidents (such as the work currently being carried out by Hurt and his colleagues at the University of Southern California). Many of these analyses provide information useful for answering the questions of current interest.

2.2.1.1 Differences Between Motorcycle-Car and Car-Car Crashes. We intuitively expect that automobiles and trucks are more conspicuous than motorcycles. If so, we should observe differences between motorcycle-car and car-car crashes.

Two prior analyses compared motorcycle-car and car-car accidents. Harano and Peck (1968) compared car-car and motorcycle-car crashes occurring in California during 1966. Polanis (1979) compared motorcycle-car crashes with car-car crashes occurring in Pennsylvania in 1975.

Harano and Peck first noticed differences between motorcycle-car and car-car crashes and found that multi-vehicle motorcycle accidents occur more often at intersections than do accidents involving only cars.

Polanis' data provide a more detailed look at the differences in multiple vehicle collisions. Table 2-1 contains the collision configuration percentages he observed. This indicates motorcycle-car collisions are more often head-on or angle collisions in comparison to car-car collisions.

In sum, these crash data show two differences between motorcycle-car and car-car crashes. First, motorcycle-car crashes tend to occur at intersections more so than car-car crashes. Second, motorcycles are more likely involved in angle collisions and head-on collisions, which implies the other driver primarily viewed the motorcycle's front silhouette. The front silhouette is small and harder to see than the side profile. These differences between car-car and motorcycle-car collisions suggest that there is a conspicuity problem.

2.2.1.2 Day-Night Differences in Conspicuity. Intuitively, motorcycles should be more conspicuous in the nighttime than in the daytime, since other drivers will be looking for vehicle lights. If so, conspicuity-related crashes should decrease in the nighttime.

Harano and Peck (1968) found a larger percentage of motorcycle accidents occur in the daytime than non-motorcycle accidents (72% motorcycle accidents versus 66% non-motorcycle accidents). A higher percentage of daytime motorcycle (or motorcycle-car) accidents in comparison to daytime car (or car-car) accidents also emerges in studies by Griffin (1974) and Waller & Griffin (1977).

The more detailed analysis of Polanis provides an indication that motorcycles are less conspicuous in the day than in the night. Table

TABLE 2-1. Percentages of multiple-vehicle collision configurations observed in Polanis' data on motorcycle and all crashes in Pennsylvania during 1975.

	COLLISION CONFIGURATION				
	Head-on	Angle	Backing Up	Side Swipe	Rear-end
% of motorcycle accidents in this configuration	1.8	55.3	1.2	1.4	9.2
% of all accidents in this configuration	1.0	40.2	2.3	2.8	19.9
Percentage ratio, i.e., motorcycle-car/ car-car	1.8	1.38	.52	.5	.46

2-2 shows that the angle collision is overrepresented in the daytime data. All the rest are virtually even odds or associated with the nighttime.

These analyses of day-night differences in crash involvement provide some evidence that motorcycles are less conspicuous in the daytime. A larger percentage of motorcycle accidents occur in the daytime than non-motorcycle accidents. Motorcycle collisions, where the other motorist views the motorcycle head-on or from an angle occur predominantly in the daytime. Unfortunately, these data are not as definitive as they might appear, because exposure data are lacking.

2.2.1.3 Does Crash Involvement Vary with the Conspicuity of the Motorcyclist? Very few data have been collected on the conspicuity of accident involved motorcyclists. The only previous examination is reported by Tratner (1978) in an interview with Hurt, the principal investigator of the USC motorcycle accident investigation project. In the interview, Hurt points out that (pg. 43):

> "...there is a spectacular absence of high visibility upper torso garments in all the accidents we tabulated. In the intersection accident, where conspicuity is critical, we found lack of conspicuous upper torso garments.... You don't see the guy riding down the street in the bright orange or day-glow orange or yellow jacket involved in an accident. It is the guy in the army surplus jacket."

Although one might argue that only the more cautious motorcyclists will wear highly conspicuous garments of their own volition, the finding indicates a strong possibility that conspicuous motorcyclists are less apt to be involved in a collision because other drivers can more easily see them.

2.2.1.4 Motorcycle-Car Crash Configurations. Two studies have examined the configuration of motorcycle-car crashes. Griffin (1974) examined the pre-crash maneuvers of both vehicles in 1,267 motorcycle-car crashes. Reiss, Berger, and Vallette (1974) examined 100 Maryland motorcycle-car crashes occurring at urban intersections.

TABLE 2-2. Polanis' analysis of day and non-day motorcycle collision configurations.

	Head-on	Pedestrian	Backing Up	Side Swipe	Rear-end	Angle	Single Vehicle	
							No Collision	Fixed Object
% motorcycle accidents occurring in this configuration in the daytime	2.8	1.9	1.3	1.5	8.3	60.8	13.3	10.1
% of accidents occurring in this configuration in the nighttime	2.7	2.5	1.3	1.7	8.1	50.6	15.1	18.0
Percentage ratio i.e., daytime/nighttime	1.04	.76	1	.88	1.02	1.2	.88	.56

Both studies obtained similar results. The motorcycle most often travels straight (78% in Griffin's data and 87% in the data of Reiss et al.) and the car is either going straight (39% in both data bases) or turning left (44% in Griffin's data and 51% in the data of Reiss et al.). Both analyses show the other motorist is maneuvering most of the time (about 60%) while the motorcycle is traveling straight most of the time (about 80%).

The crash configuration of a motorcycle traveling straight and a car maneuvering provides additional evidence that a conspicuity problem exists. If no conspicuity problem existed, we would expect little difference in pre-crash direction of travel between cars and motorcycles. Furthermore, the evidence suggests that special effort should be directed at the conspicuity of motorcycles to the front.

2.2.1.5 Culpability in Motorcycle Crashes. Both Waller (1972) and Reiss, Berger, and Vallette (1974) examined other motorist culpability in motorcycle-car crashes. Culpability can serve as a surrogate measure of conspicuity as it implies a failure to see, identify, or respond appropriately to a motorcycle. Waller's analysis of the 630 multivehicle motorcycle accidents reported in North Carolina in 1968 concluded that 62.2% were caused by the other driver. Reiss, Berger, and Vallette's analysis of a sample of 400 1973 Maryland multivehicle motorcycle accidents concluded that the other driver was culpable in 61.1% of these accidents.

2.2.2 Foreign Motorcycle Accident Experience. Foreign motorcycle analyses have primarily examined configurations of motorcycle-car crashes. Of these, we have chosen one from Australia (Smith, 1975) and one from Japan (Nagayama, et al., 1979) because of the detail they provide.

Smith examined configurations of motorcycle-car crashes in Australia along with the errors made by the motorcyclist and car operator. His data indicate the car driver most often erred in turning right (Australians drive on the left) or in failing to yield at an intersection. These results closely correspond to those of Griffin, Berger, et al., and Polanis for the U.S.

A similar profile is observed in the Japanese data of Nagayama, Moritu, Miura, Watanabem, and Murakami (1979). Japanese motorcycle-car crashes involve straight traveling motorcycles (86%) and right turning (Japanese drive on the left as well) (20.9%) or straight traveling (14.3%) cars.

2.2.3 Summary and Conclusions. Both U.S. and foreign motorcycle accident analyses point to conspicuity as a real problem. A comparison of motorcycle-car and car-car crashes shows differences suggesting other drivers have difficulty seeing and identifying motorcycles. Since similar patterns are observed world-wide, the conspicuity problem likely does not stem from lack of experience in dealing with motorcycles on the part of U.S. drivers.

Specifically, these patterns emerge from the data:

- A higher percentage of motorcycle-car crashes occur at intersections than car-car crashes.
- A higher percentage of motorcycle-car crashes are angle or head-on collisions than car-car crashes.
- Motorcycle-car accidents tend to occur during the day.
- Motorcycle-car accidents, where the vehicles collide at an angle, occur predominately in daytime.
- The most prevalent motorcycle-car crash configurations involve a straight traveling motorcycle and a car which is
  - turning left, or
  - traveling straight
- The car driver is culpable in about 60% of all car-motorcycle crashes.
- Motorcyclists wearing highly conspicuous upper garments are underrepresented in the accident population.

2.3 HSRI Motorcycle Accident Analysis

This analysis was carried out using computerized data files at HSRI. The aim was to secure additional detailed information which might aid in identifying critical situations and possibly countermeasures.

2.3.1 Method. All motorcycle crashes occurring in Texas during, 1975 were selected for examination. This sample contains about 10,000 crashes and represents about 10% of all U.S. motorcycle crashes in 1975. A second sample of 5% of all motor vehicle crashes occurring in Texas in 1975 was used in selected comparisons

A two-stage analysis procedure was employed: in the first stage, percentage profiles of motorcycle accidents were developed, e.g., how many occurred in the daytime versus the nighttime. The second stage selectively compared the motorcycle crash profiles where the comparison would provide information on conspicuity.

2.3.2 Results.

2.3.2.1 Motorcycle-Car Crashes Compared with Car-Car Crashes. Table 2-3 breaks down the pre-crash vehicle maneuvers in the 6,467 motorcycle-car crashes in Texas during 1975. ("Car" includes both automobiles and trucks.) This matrix is very similar to Griffin's data (1974). The marginal percentages show that motorcycles are traveling straight in about 87% of these crashes whereas other vehicles were traveling straight in only about 46% of the crashes. (Griffin reports figures of about 78% and 39%, respectively.)

Two cells dominate this analysis. In both of these cells the motorcycle is traveling straight and in one the car is also traveling straight and in the other it is turning left. Left turns or straight crossings can be difficult maneuvers, providing an opportunity for conflict with other traffic in one or both directions.

TABLE 2-3. Pre-crash maneuvers in 6647 motorcycle-car crashes--Texas 1975. Frequencies are above percentages in each cell.

Car's Maneuver	Motorcycle's Maneuver						
	Straight	Right Turn	Left Turn	Back	Stopped	Parking	Row Total
Straight	2378 35.8	130 2.0	347 5.4	4 0.0	216 3.2	4 0.0	3089 46.4
Right Turn	430 6.5	23 0.3	11 0.2	0 0.0	4 0.0	0 0.0	468 7.0
Left Turn	2388 35.9	15 0.2	32 0.5	0 0.0	8 0.0	0 0.0	2443 36.7
Back	88 1.3	0 0.0	0 0.0	0 0.0	25 0.4	0 0.0	113 1.7
Stopped	457 6.9	12 0.2	7 0.1	0 0.0	0 0.0	0 0.0	476 7.2
Parking	53 0.8	5 0.1	0 0.0	0 0.0	0 0.0	0 0.0	58 0.9
Column Total	5794 87.2	185 2.8	407 6.2	4 0.0	253 3.7	4 0.0	6647 99.9

Table 2-4 compares marginal percentages of the pre-crash maneuvers in motorcycle-car crashes with the car-car situation. The car pre-crash maneuvers are very similar in both situations, except for the left-turns and stopped pre-crash states: Cars are more likely to be turning left in motorcycle-car crashes than in car-car crashes; cars are more likely to be stopped in car-car crashes than in motorcycle-car crashes.

Table 2-5 shows the relative direction of travel in motorcycle-car crashes involving a left turn. A chi-square test indicates a dependency within the matrix, which, by inspection, stems from the large number of crashes involving the car turning left and the vehicles traveling in the opposite direction.

Table 2-6 shows a similar analysis of 1974 Texas automobile-truck crashes involving a left turn. A chi-square test shows no dependency in this table.

A comparison of Tables 2-5 and 2-6 suggests that a major difference between car-motorcycle and car-car accidents is in those cases where a car is making a left turn in front of an approaching motorcycle. This argues against perversity as an explanation, since it does not seem reasonable that drivers would behave perversely in only one maneuver.

2.3.2.2 Summary. Our comparison of motorcycle-car and car-car crashes has shown these points:

- In the prepondence of motorcycle-car crashes:
    - the motorcycle is traveling straight
    - the car is maneuvering, most often turning left
- Cars are more likely to be maneuvering in motorcycle-car crashes than in car-car crashes.
- These accident profiles provide strong support for concluding that motorcycle conspicuity is a serious problem.

TABLE 2-4. A comparison of marginal percentages of motorcycle and car pre-crash maneuvers with the car-car situation.

	Straight	Right Turn	Left Turn	Back	Stopped	Park
Motorcycle N=6647 Texas 1975 Crashes	87.2	2.8	6.2	0	3.4	0
Car N=6647 Texas 1975 Crashes	46.4	7.0	36.7	1.7	7.2	.9
Car-Car N=16353 Texas 1975 Crashes	39.7	7.6	22.9	2.7	24.4	2.7

TABLE 2-5. Relative travel direction in 1975, Texas motorcycle-car accidents involving one vehicle going straight, the other turning left. $X^2 = 130.6$, df = 2, $p < .001$. Frequencies are above percentages in each cell.

Vehicle Turning Left	Relative Travel Direction			
	Angle	Same	Opposite	Row Total
Motorcycle	142 5.2	122 4.5	83 3.0	347 12.7
Car	549 20.1	485 17.7	1354 49.5	2388 87.3
Column Total	691 25.3	607 22.2	1437 52.5	2735 100.0

TABLE 2-6. Relative travel direction in 1975, Texas car-truck accidents involving one vehicle going straight and the other turning left. $\chi^2 = .818$, df = 2, $p > .5$. Frequencies are above percentages in each cell.

Vehicle Turning Left	Relative Travel Direction			
	Angle	Same	Opposite	Row Total
Truck	137 17.7	144 18.6	126 16.3	407 52.6
Car	134 17.3	128 16.5	105 13.6	367 47.4
Column Total	271 35.0	272 35.1	231 29.9	774 100.0

2.3.2.3 Day-Night Differences in Motorcycle Crashes and Conspicuity. Table 2-7 presents the time-of-day breakdown of single- and two-vehicle 1975 Texas motorcycle accidents. The table shows that motorcycle accidents tend to occur in the day (72%). Two-vehicle accidents are more likely to occur in the day than are single-vehicle accidents (76.9% vs. 59.4%), while single-vehicle accidents occur twice as often as two-vehicle accidents at night (28.6% vs. 14.7%).

Table 2-8 examines the types of motorcycle and car crashes that occur during daylight and non-daylight hours. For both motorcycles and cars, there is a higher percentage of single-vehicle crashes during non-daylight hours. In contrast, during the day, multiple-vehicle crashes are predominant for both types of vehicle. In comparison with cars, motorcycles have more daytime single-vehicle crashes, and, for both day and non-day, more crashes where the other vehicle is turning. Cars, in comparison to motorcycles, are involved in more multiple-vehicle collisions in the daytime with both vehicles traveling forward and in both daytime and non-daytime with one vehicle stopped. In general though, Table 2-8 shows a similar breakdown of crashes by light condition for both motorcycles and cars.

Table 2-9 and 2-10 provide a closer examination of the light-condition differences observed for motorcycles in Table 2-8. Displaying motorcycle-car data, both tables contrast the pre-crash maneuvers of the motorcycle with that of the car. Table 2-9 is for daytime data; Table 2-10 is for non-daytime data. Although fewer multi-vehicle motorcycle crashes occur in non-daylight hours, as indicated in Table 2-8, the pattern of motorcycle-car crashes remains constant across light conditions.

Tables 2-11 and 2-12 show that some daytime versus nighttime differences in motorcycle accidents appear to be dependent on the color of clothes worn by motorcyclists. Table 2-11 is for single-vehicle motorcycle crashes, Table 2-12 is for motorcycle-car crashes. Darker colors tend to be involved with nighttime crashes, especially in the two-vehicle groups (Table 2-12).

TABLE 2-7. Time-of-day versus number of vehicles in 1975, Texas motorcycle accidents.

	Day	Night	Night with Street Lights	Dawn	Dusk	Row Totals
Single						
Frequency	1676	808	258	14	67	2823
Row %	59.4	28.6	9.1	0.5	2.4	100.0
Col %	23.1	43.0	37.4	42.4	30.3	28.0
Tot %	16.6	8.0	2.6	0.1	0.7	28.0
Motorcycle-Car						
Frequency	5591	1072	431	20	154	7268
Row %	76.9	14.7	5.9	0.3	2.1	100.0
Col %	76.9	57.0	62.6	57.6	69.7	72.0
Tot %	55.4	10.6	4.3	0.2	1.5	72.0
Column Totals						
Frequency	7267	1880	689	34	221	10091
Row %	72.0	18.6	6.8	0.3	2.2	100.0
Col %	100.0	100.0	100.0	100.0	100.0	100.0
Tot %	72.0	18.6	6.8	0.3	2.2	100.0

TABLE 2.8. Light conditions in motorcycle and car collisions, Texas motorcycle accidents, 1975.

MOVEMENTS OF THE VEHICLE	DAY		NON-DAY	
	CYCLE/CAR	CAR/CAR	CYCLE/CAR	CAR/CAR
Single Forward	23.6	14.0	40.8	43.6
Single Turn	2.7	2.2	4.3	3.9
Single Back	0	2.9	0	2.8
Both Forward	27	32.6	20.6	21.9
Forward/Turn	36.6	23.7	26.3	14.7
Forward/Back	1	2.2	.7	.8
Forward/Stop	7.6	18	6.1	9.9
Turn/Turn	.9	1.7	.7	1
Turn/Back	0	0		
Turn/Stop	.4	1.1	.2	.9
Back/Back	0	.3		.1
Back/Stop	.3	1.2	.2	.4

LEFT TURN ANALYSIS

TABLE 2-9. Daytime left-turn motorcycle-car collisions, Texas motorcycle accidents, 1975.

DAY	Angle	Same	Opposite
Motorcycle	137 6%	102 4%	62 2%
Car	415 19%	397 18%	1045 48%

TABLE 2-10. Non-day left-turn motorcycle-car collisions, Texas motorcycle accidents, 1975.

NON-DAYTIME	Angle	Same	Opposite
Motorcycle	11 2%	70 3%	21 3%
Car	120 22%	81 15%	273 51%

TABLE 2-11. Color of upper garment worn by 1975 Texas motorcyclists involved in single-vehicle crashes, classified by time of day of accident.

	Day	Night	Night with Lights	Totals
White				
(Frequency)	194	76	28	298
(Row %)	65.1	25.5	9.4	
(Col %)	22.4	16.2	19.6	
(Tot %)	13.1	5.1	1.9	20.1
Yellow				
(Frequency)	41	16	4	61
(Row %)	67.2	26.2	6.6	
(Col %)	4.7	3.4	2.8	
(Tot %)	2.8	1.1	0.3	4.2
Blue				
(Frequency)	364	190	54	608
(Row %)	59.9	31.3	8.9	
(Col %)	42.0	40.6	37.8	
(Tot %)	24.6	12.9	3.7	41.2
Brown				
(Frequency)	100	56	27	183
(Row %)	54.6	30.6	14.8	
(Col %)	11.5	12.0	18.9	
(Tot %)	6.8	3.8	1.8	12.4
Black				
(Frequency)	39	39	9	87
(Row %)	44.8	44.8	10.3	
(Col %)	4.5	8.3	6.3	
(Tot %)	2.6	2.6	0.6	5.8
Green				
(Frequency)	80	49	12	141
(Row %)	56.7	34.8	8.5	
(Col %)	9.2	10.5	8.4	
(Tot %)	5.4	3.3	0.8	9.5
Red				
(Frequency)	48	42	9	99
(Row %)	48.5	42.4	9.1	
(Col %)	5.5	9.0	6.3	
(Tot %)	3.2	2.8	0.6	6.6
Column Totals				
(Frequency)	866	468	143	1477
(Total %)	58.5	31.6	9.7	99.8

TABLE 2-12. Color of upper garment worn by 1975 Texas motorcyclists involved in two-vehicle crashes, classified by time-of-day of accident.

	Day	Night	Night with Lights	Totals
White				
(Frequency)	539	87	33	659
(Row %)	81.8	13.2	5.0	
(Col %)	23.3	18.0	15.1	
(Tot %)	17.9	2.9	1.1	21.9
Yellow				
(Frequency)	122	13	6	141
(Row %)	86.5	9.2	4.3	
(Col %)	5.3	2.7	2.8	
(Tot %)	4.1	0.4	0.2	4.7
Blue				
(Frequency)	925	217	87	1229
(Row %)	75.3	17.7	7.1	
(Col %)	40.1	44.8	39.9	
(Tot %)	30.7	7.2	2.9	40.8
Brown				
(Frequency)	270	72	35	377
(Row %)	71.6	19.1	9.3	
(Col %)	11.7	14.9	16.1	
(Tot %)	9.0	2.4	1.2	12.6
Black				
(Frequency)	80	29	16	125
(Row %)	64.0	23.2	12.8	
(Col %)	3.5	6.0	7.3	
(Tot %)	2.7	1.0	0.5	4.2
Green				
(Frequency)	237	38	26	301
(Row %)	78.7	12.6	8.6	8.6
(Col %)	10.3	7.9	11.9	
(Tot %)	7.9	1.3	0.9	10.1
Red				
(Frequency)	136	28	15	179
(Row %)	76.0	15.6	8.4	
(Col %)	5.9	5.8	6.9	
(Tot %)	4.5	0.9	0.5	5.9
Column Totals				
(Frequency)				
(Total %)	76.8	16.1	7.3	100.2

2.4 Summary

In general, the crash data indicate the following five answers are the best to the questions posed in Section 2.1.

- Differences in patterns of motorcycle-car and car-car crashes suggest that other drivers do sometimes fail to see or identify motorcycles, i.e., conspicuity appears to be a factor in motorcycle crashes.
- Crash data are inconclusive on a day-night difference in motorcycle conspicuity.
- Crash data do suggest crash involvement decreases with increased motorcyclist conspicuity.
- The most prevalent motorcycle-car crash configuration, in both the day and night, involves a straight traveling motorcycle, and a left-turning car.
- Estimates of the number or percentage of crashes involving conspicuity is very difficult due to the necessity of making some rather tenuous assumptions. The culpability data suggest it may be a factor in about 10% of all motorcycle-car crashes (about 60% of the time the car driver is judged at fault when chance dictates each should be culpable 50% of the time).

3.0 SEEING AND REACTING TO MOTORCYCLES

3.1 Introduction

Based on analyses of driver performance (see, e.g., Alexander & Lunenfeld, 1975; Fell, 1976; and Shinar, 1978), one can postulate three stages of processing in a driver's sensory-cognitive response to a moving motorcycle. These stages are:

1. Detection
2. Identification
3. Decision

Detection implies that sufficient visual stimulus has been provided to cause the observer to realize that "something" is there. Typically, as will shortly be described, detection is peripheral and an eye movement called saccade is made to permit the "something" to be studied in the foveal portion of the eye.

The identification stage involves the acquisition of sufficient information about the object of concern to be able to make a proper decision regarding action to be taken. Thus, if the object is a moving vehicle, as in the case of a motorcycle, the driver must, at a minimum, recognize the object as a vehicle with high performance characterisitcs and make some estimate of its distance and speed.

With the identification process complete, the driver must decide an appropriate course of action. Typically, in the present context, this will be a go or no-go decision. The decision is influenced in part by factors other than those acquired in the identification stage. For example, a driver in a hurry or who has waited a long time may accept a gap in traffic that would normally be rejected. It could also be influenced by factors such as prejudice, conceivably leading some drivers to deliberately engage in actions dangerous to motorcyclists.

Thus, motorcycle crashes which appear to be conspicuity-related could actually arise from one or more of the following:

Failure to detect.

Misidentification (e.g., "bicycle" rather than "motorcycle").

Errors in speed-spacing judgments.

Inappropriate decision (e.g., based on excessive haste or prejudice against motorcycles).

Inappropriate decisions based on haste, drugs, or factors other than prejudice can be ruled out as an explanation of the data presented in Section 2.0, as they should apply equally to cars and motorcycles. This still leaves a minimum of four possible problem areas which may account, in some combination, for the accident patterns noted.

3.2 The Functional Implications of the Structure of the Retina: Foveal vs. Peripheral Vision

From the functional point of view, the human retina (the part of the eye where the image becomes focused) can be divided into two main regions, the fovea and the periphery. The fovea is the area of the retina corresponding to the central 1-2° of the visual field (Polyak, 1941) and the periphery corresponds to the remainder of the visual field. Important differences between the roles of the fovea and the periphery in visual information processing are discussed below.

In photopic and mesopic light conditions, the luminance threshold is lowest at or near the fovea and decreases with increasing retinal periphery (Aulhorn & Harms, 1972). In scotopic light conditions the peak sensitivity is obtained at 15°-20° in the periphery (Aulhorn & Harms, 1972; Pirenne, 1967). However, most of the driving is done under photopic or mesopic conditions (Cole, 1972; Projector & Cook, 1972; Schmidt, 1966). Therefore it can be argued that in most driving situations the luminance threshold is lowest at or near the fovea.

The fovea is tightly packed with wavelength (color) sensitive cones (Osterberg, 1935). Since there is a sharp decrease in the frequency of the cones outside of the fovea (Osterberg, 1935), color discrimination is best in the fovea and decreases with increased eccentricity from the fovea (Moreland, 1972; Walls, 1942).

The threshold for motion detection (despite popular belief to the contrary) is lowest in the fovea; i.e., the threshold speed is lower at or near the fovea than in the periphery (Aubert, 1886; Gordon, 1947; Klein, 1942; McColgin, 1960).

Acuity refers to the ability to resolve fine detail, and one manifestation of good acuity is efficient identification of form. Acuity (and consequently form perception) is best at or near the fovea and decreases with increasing eccentricity from the fovea. The superior acuity of the fovea holds whether the target is moving in relation to the observer, so-called dynamic acuity (Gordon, 1947; Klein, 1947; Low, 1947), or is stationary in relation to the observer, so-called static acuity (Aulhorn & Harms, 1972; Brown, 1972; Feinberg, 1948; Green, 1970; Held, 1959; Hershenson, 1969; Kerr, 1971; Low, 1951; Ludwigh, 1941; Mandelbaum & Sloan, 1947; Wertheim, 1894).

As mentioned above, the periphery of the retina includes the whole visual field except the central 1-2° of the fovea. In the horizontal meridian the active binocular visual field (the area in which one can detect the presence of an object) extends to about 175-180°; in the vertical meridian it extends to about 100-130° (Burg, 1968; Connolly, 1966; Schmidt, 1966).[1] Since the periphery comprises more than 99% of the active visual field, the likelihood of the image of an object falling on the periphery as opposed to the fovea is high. However, as already noted, acuity and consequent form identification is rather inefficient in the periphery. Therefore, most objects have to be identified in the fovea (Waldram, 1960).

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[1] The extent of the active visual field varies with the size of the target to be detected. Furthermore, there is a general shrinkage of the active visual field with age (Burg, 1968; Wolf, 1967). The values presented here apply for young observers.

3.2.1 The Peripheral Filter. The functional differences between the fovea and the periphery led several researchers to postulate different processing modes of these regions of the retina (Boynton, 1960; Mackworth & Bruner, 1970; Mourant & Rockwell, 1970; 1971; Schiffman, 1972; Treverthen, 1968). These authors argue that the periphery is involved primarily in the monitoring and detection processes, while the fovea is involved primarily in the indentification process. However, identification by the fovea requires sequential shifting of the fovea to different spatial locations, resulting in a generally serial identification process, while the detection process within the visual field is essentially parallel. Because of the sequential limitation of the identification process and because of the relatively large size of the periphery in comparison to the fovea, it is usually impossible to identify all the targets detected by the periphery. Therefore, it is reasonable to postulate, as did these authors, that the results of peripheral processing will selectively determine where the foveal attention will be directed. In other words, a peripheral filter is postulated which filters (gates) the information irrelevant to the task in order for the relevant information to be more thoroughly inspected by the fovea (Boynton, 1960; Hochberg, 1970; Howett, Kelly, & Pierce, 1978; Mackworth & Bruner, 1970; Mackworth & Morandi, 1967; Mourant & Rockwell, 1970; Townsend & Fry, 1960).

The determination of the relevant parameters for the peripheral filter comes from several types of investigations: eye or head movement monitoring, conspicuity evaluation, and detection threshold determination. If subjects are told to search for specified targets (e.g., given size or shape), they are less likely to fixate on the irrelevant targets (Williams, 1970). This indicates that some preliminary categorization is taking place even in the periphery. In a free-search situation, where the person is under no instruction, the eye-movement studies indicate that the fovea is attracted towards high-information points of the display (Mackworth & Morandi, 1967; Notton & Stark, 1971; Yarbus, 1967), high-contrast areas (Thomas, 1968), flickering stimuli (Thomas, 1968; 1969) large-sized stimuli (Thomas, 1968), or moving objects (Thomas, 1968).

Studies monitoring visual searches (eye and head movements) indicate that there is an increase in visual searches with an increase in the amount of traffic (Robinson, 1972; Robinson, Clark, Erikson, & Thurston, 1971). These findings suggest that the relevant visual target for the driver to detect, fixate upon, and identify might be moving objects.

It is known (Bartley, 1938; Gerathewohl, 1953; 1957; Halstead, 1941) that flashing lights are generally more conspicuous than steady lights, whether the conspicuity is measured in terms of apparent brightness or reaction time.[2] Therefore, it is reasonable to assume that under certain conditions a flashing light will be more likely to result in a fixation than a steady light.

It can be assumed that in a free-search situation an object that is more likely to be detected will more likely be fixated upon and thereby more likely identified. It is well known that the detectability of a target is affected by its size, luminance, and contrast.[3] With an increase in the size of a stationary target there is a decrease in the luminance or contrast threshold; conversely, with an increase in target luminance or contrast there is a decrease in the size threshold (Austin, 1951; Blackwell, 1946; 1959; Brown, 1947; Graham & Bartlett, 1939; Graham, Brown & Mote, 1939; Hills, 1976; Krisstofferson, 1954; Lamar, Hecht, Schlaer, & Hendley, 1947; Riopelle & Chow, 1953; Taylor, 1964). Therefore, it can be assumed that larger, brighter, or more contrasting stimuli will be more frequently fixated.

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[2] This advantage of the flashing light is absent in the presence of other flashing lights (Crawford, 1962; 1963).

[3] The luminance is the variable of interest if the background luminance is zero; contrast if the background luminance is not equal to zero.

3.2.2 Eye Movements and Saccadic Suppression. The change of the fixation point is most frequently achieved by a fast jumping eye movement, called the saccade. A saccadic eye movement can be elicited voluntarily or it can be triggered by a peripheral stimulus, whether visual or auditory. Kestenbaum (1961) refers to a saccade triggered by the peripheral visual stimulus as the optically elicited movement (OEM). According to Kestenbaum, an OEM (a saccade) is "elicited by an object situated in any place of the visual field, except the fovea, when this object attracts the attention [i.e., it passes the peripheral filter]" (p. 300). The saccadic movement "is semi-reflex, occurring without conscious volition but depending on attention and capable of suppression (Cole, 1972, p. 108)."

The importance of saccades in the present context lies in their effect on the visual processing. There is extensive evidence that during the saccadic eye movements the visual capabilities are reduced. If the target is stationary, this saccadic suppression is evident whether the visual performance is measured in terms of a decrease in the probability of detection, in terms of a decrement in detection sensitivity (as measured for example by $\underline{d}'$), or in terms of an increase in the luminance threshold (Beeler, 1967; Latour, 1962; Mitrani, Yakimoff & Matteeff, 1970; Pearce & Porter, 1970; Richards, 1969; Volkman, 1962; Volkman, Schick & Riggs, 1968; Zubek & Stark, 1966). If the target is moving, the saccadic suppression is manifested by a decrease in the probability of the motion detection or decrease in the probability of correctly identifying the direction of the motion (Beeler, 1967; Ditchburn, 1955; Holly, 1975; Sperling & Speelman, 1965; Wallach & Lewis, 1965).

3.2.3 Implications for Motorcycles. In order to illustrate what the concepts and processes described above mean for motorcycle conspicuity, consider the following example:

Assume that a car is attempting to merge into a primary road from a secondary road. In the search of the intersection, the driver of the car is likely to execute first a voluntary saccade and/or a head movement of a fixed magnitude, say to the left. However, the contention here is that his further eye movements (at least in the leftward direction) will be guided by the objects passing the peripheral filter. In a case of no traffic near the intersection, there might not be any object passing the peripheral filter and the driver's gaze would shift to the right of straight ahead and repeat the search in the rightward direction. Again, if there is no traffic, no objects will pass the peripheral filter and the driver will proceed to the planned maneuver. (The whole cycle of the search--leftward and rightward--is sometimes repeated several times before making the maneuver, as in the case of a cautious driver.)

Now assume that there is some traffic at the intersection, but the traffic is light, say a car and a motorcycle both approaching from the left. After executing the left (voluntary) saccade, there will be only two moving objects (the car and the motorcycle) competing for foveal attention. In such a situation, the peripheral filter would likely pass both objects (sequentially), resulting in at least one fixation on each of the two vehicles. Such a pattern of fixations would result in high probability of correctly identifying both vehicles and taking the proper action.

In a heavy traffic, however, there might be dozens of vehicles approaching the intersection from both sides. The possibility is that if there is a motorcycle within the approaching traffic, it will be less likely than other vehicles to pass the peripheral filter and thus will be less likely to trigger a saccade than the larger-sized vehicles (cars and especially trucks). The resulting lower probability of fixations on the motorcycles would make them less likely to be identified because of their remaining in the periphery and because of the consequence of saccadic suppression.

In terms of Signal-Detection theory (Green & Swets, 1966) it could be argued that the amount of traffic has an effect on the decision criterion (β) but not on the sensitivity (d'). (The criterion here is the criterion of the peripheral system for the initiation of a saccade.) Therefore, it is proposed that in conditions ranging from no traffic through light to moderate traffic the criterion is low, resulting in situations where even objects with less favorable physical characterisitcs (e.g., smaller size) would trigger saccades and lead to fixations. Throughout this range of conditions the criterion would remain constant, since the foveal capacity for the frequency of fixations (2-4/sec., Cole, 1972) might be reached only in the moderate traffic. However, with a further increase in the amount of traffic the criterion for the initiation of a saccade is increased since the limit of the essentially serial identification processing by the fovea (frequency of fixations) has been reached. In heavy traffic there are many potential peripheral candidates (for the approximately 2-4 fixations/sec.) and therefore the selection process has to be more stringent. These conditions may lead to the rejection of targets which would not be rejected in lighter traffic (e.g., motorcycles).

3.2.4 Conclusions. On the basis of this analysis, it can be concluded that motorcycles are less likely to be detected and to pass the peripheral filter and thus less likely to be identified because of the following considerations:

First, the physical features of motorcycles (especially their smaller size) make them more likely to be closer to (if not below) peripheral thresholds than those same features for automobiles. This implies that motorcycles are less likely to be detected, resulting in a diminished likelihood of their passing the peripheral filter and therefore a diminished likelihood of being subjected to subsequent processing (e.g., being fixated upon and identified in the fovea).

Second, even if detected, motorcycles are less likely to trigger saccades, which would result in a foveal fixation on them. That is, the probability that motorcycles would occupy the area of the retina most efficient at motion detection, acuity, and color discrimination--the fovea--is reduced from that of automobiles. The higher threshold speed for motion detection in the periphery would result in high probability of misperceiving such moving objects as being stationary. The poor acuity and consequently inaccurate form perception would lead to a low rate of correct identification of motorcycles.[4]

Third, motorcycles will be likely to fall on the fovea only during saccades, since they are unlikely to be the terminal points of saccades (the fixation points). Therefore, the effect of the saccadic suppression will be more detrimental to the identification of motorcycles. In other words, the objects that do not pass the peripheral filter occupy the fovea only during saccades; the objects that pass the peripheral filter occupy the fovea during fixations as well. This situation results in the objects not passing the peripheral filter having a decreased probability of correct identification, since the identification during saccades is less efficient than during fixations.

3.3 Critical Cues

Our analysis of the critical cues for motorcycle identification is based on Henderson and Burg's (1974) analysis of driver visual requirements. Table 3-1 shows a list of critical cues for identifying a motorcycle. Generally speaking, other drivers identify motorcycles based on the motorcycle's motion, color, form, shape, size, luminance, or some combination of these cues.

Many drivers probably use a special priority ordering or combination of these cues to identify a motorcycle. For example, a North Carolina[5] resident might identify all moving single headlamps as

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[4] The assumption is that a fixation might be a necessary condition for efficient identification. No claim is being made that it is also a sufficient condition for efficient identification, since it is known that a fixation on an object does not guarantee its identification (Thomas, 1968).

[5] North Carolina currently has a motorcycle lights-on law.

TABLE 3-1. Types of critical cues for identifying a motorcycle.

Cue	Cue Definition
Angular movement	Lateral motion vector component
Movement in depth	Closure motion vector component
Color	Perceived color
Color contrast	Perceived color differences between object and background
Form	Elementary geometric element, e.g., line, circle
Shape	Complex geometric structure, e.g., two-wheels, handlebars
Size	Retinal image size
Luminance	Perceived brightness
Luminance contrast	Perceived brightness differences between object and background

motorcycles. However, we currently do not know the actual patterns of cues drivers use to identify motorcycles. Thus, we do not know which pattern of cues is the most critical for identifying a motorcycle.

Given this knowledge gap, we cannot proceed straightforwardly to discuss just how a motorcycle is identified. Instead, we must examine how drivers perceive each of these cues.

In general, perception of the color, luminance, form, and shape cues is no different for motorcycles than for any other vehicle, except that smaller size produces difficulty in perceiving them. A major difficulty appears in perceiving motion. Two cues are considered here as providing information necessary for motion perception. The motion-in-depth type of cue allows the perception of relative closure. The angular motion type of cue allows perception of lateral movement. Since the motion-in-depth cues are most affected by vehicle size, and because it is a type of cue involved in almost all motion perception in driving, they will be focused upon in our discussion here.

3.3.1 Motion Perception. Michaels (1963) postulates a two-stage model of the process involved in detecting closure and relative speeds by the driver of a car following another car. The first stage applies to those cases where the time rate of change in the lead car's image size is too slow to be perceived directly. In this case detection is thought to be accomplished by comparing the present image with a remembered image. At higher time rates of image size change, the observer can directly sense rate and likely use this as a basis for judgment. Thus, below the threshold for detection of motion, sensitivity is based on the ability to make judgments of size change on an absolute basis, Michaels estimates the Weber ratio (Δ image size/image size) in this task to be about 0.1. The threshold for detection of rate of change of the size of the image of a lead car is estimated by Michaels to be about 6×10^{-4} rad/sec (about 2 minutes of arc per second).

Hoffman (1968) has elaborated on Michaels' model. Following the line of his 1966 paper, Hoffman reanalyzed the data from several studies (such as those described below) to determine whether performance seemed to be in accord with predictions based on a two-stage process. He feels that the results do support such a model, although he argues that there is probably a range of rates wherein both absolute judgment and rate detection operate. Hoffman also reports that a low (sub-threshold) time rate of change in lead car image size detection was "degraded by the presence of these angular velocities."

No comprehensive investigations of the validity of Michaels' model have been reported. However, Salvatore (1965) has investigated sensitivity to the size change cue. On an oscilloscope he displayed a bar representing the width of a car. By changing the length of the bar he simulated three spacings and presented two rates of change in bar length deemed sub-threshold (34 and 102 seconds of arc per second). The dependent variable was response time. Salvatore reports shorter response times for the higher rate but the Weber ratio for change in visual angle was somewhat less for the lower rate. It was also found that the Weber ratio decreased from about 0.13 for a 1.5^0 target to 0.065 for a 6^0 target.

Using a different procedure, Vincent et al. (1969) have also studied sensitivity to size change. Their target, an Apollo command and service module, presented a target size of about 13 x 24 feet and was viewed statically for three seconds, obscured for three seconds, and viewed again in a different size for three seconds. They reported ratios of 0.028 at 200 feet, 0.029 at 400 feet and 0.03 at 800 feet. Beyond 800 feet the Weber ratio increased and was reported as 0.065 at 12,800 feet, the greatest viewing distance used.

A similar procedure was used by Olson (1971) for automobile targets at viewing distances up to 300 feet in both laboratory and field investigations. The Weber ratio was 0.03 for all conditions.

There has been interest in measuring thresholds for angular motion for many years. A number of these investigations have been summarized by Brown (1960), who points out that the least detectable difference in speed (Δ W) varies in direct proportion to speed over a range of 0.1^{0} to 20^{0} visual angle per second. The Weber ratio Δ W/W is equal to 0.1.

The work to which Brown refers is based on motion in a plane normal to the observer's line of sight. The motion of interest in this review is of the edges of the image of a lead vehicle, produced as the image increases or decreases in angular size. It is not obvious that sensitivity to the two types of motion should be directly related.

The rate threshold of 6×10^{-4} rad/sec assumed by Michaels is based on the results of an investigation of another driving situation (Michaels and Cozan, 1963), where an attempt was made to isolate the variables by means of which the driver locates himself relative to fixed objects in or near his path. The authors measured lateral displacement of a vehicle as a function of its speed and the position of a roadside obstacle. They interpreted their results to mean that drivers were using as a cue to object position the perceived lateral velocity of the obstacle and deduced the above value as a perceptual threshold.

Baker and Steedman (1961) have reported data on the sensitivity of observers to movement in depth. They used a luminous disc which could be moved toward or away from the subject in an otherwise totally dark field. The first study investigated the effect of target luminosity. The target subtended an angle of 0.0117 radian (equivalent to a six-foot wide car viewed at 513 feet) and was moved toward or away from the subject to produce an initial rate of change in size of 1.29×10^{-4} rad/sec. Exposure durations were controlled at six levels. The results indicated improved performance both as target luminosity and exposure durations increased.

A second study reported in the same paper held target luminosity constant and varied target speed and exposure duration. Target speeds produced initial rates of change in target image size of 0.64, 1.29, 2.57, and 5.5 x 10^{-4} rad/sec. Exposure durations varied from 0.15 second to 13.2 seconds. The results indicated improved performance associated with higher rates and longer viewing times. For instance, given a viewing time of 0.9 second, subjects correctly identified the direction of travel 95% of the time at the highest rate, 85% of the time at the second highest rate and 60% of the time at the third highest rate.

In another study, the same authors (Steedman and Baker, 1962), investigated the effect of stimulus size on the capability of subjects to detect movement in depth. The apparatus was the same as in the earlier study. Six targets sizes were used, ranging from 0.0176 radian to 0.00044 radian. Exposure durations ranged from 0.4 to 16.46 seconds. The target first became visible at a viewing distance of 300 inches and moved at a constant speed of six inches per second. With target speed fixed, the initial rate of change in angular size, measured in radians per second, was directly related to target diameter. For instance, the initial rate for the largest target was 3.52 x 10^{-4} rad/sec, the initial rate for the next largest target was half this value and so on. The results show a steady improvement in performance as larger targets were used. Unfortunately, the design of the study does not permit the separation of target size from rate of change in size.

Granting that the stimuli are quite different from a car viewed against a roadway environment, these two studies, particularly the first one, offer a chance to check the model proposed by Michaels. According to this model, below a rate of 6 x 10^{-4} rad/sec a given percent change in size should produce performance equivalent to static, absolute judgments (75% correct for a 3% change, based on Vincent et al., 1969). Indeed, performance at the lowest rate used (.64 x 10^{-4} rad/sec) was about 75% correct at 3% change, although it increases to 80-85% correct at higher rates. At the highest rate (5.15×10^{-4} rad/sec) 3% performance began to deteriorate relative to the intermediate rates although, as pointed out by the authors, this may be attributable to the very short viewing times (approximately 0.5 second) involved.

Although the data are sparse, they do lend some support to the model. Since a rate of 6×10^{-4} rad/sec was not attained, one cannot be certain that performance does not stabilize above that level and the gradually increasing performance at middle rates could be attributable to the "dual mode" zone proposed by Hoffman. Clearly more evidence is required before the model can be regarded as valid.

An interesting model of motion perception has been proposed by Kinchla and Allan (1969). According to this model an image of a target is stored at time $\underline{k}$. At time $\underline{k} + \underline{t}$, where $\underline{t}$ denotes a decay time, a comparison is made with the altered image. The probability of detecting whether an object is in motion depends on the decay rate and the time between comparisons. In a situation where the conditions are relatively constant and the decay rate is fixed the model predicts performance varying as a function of extent of change with short $\underline{t}$'s and a drop to chance levels of performance as $\underline{t}$ becomes long.

Olson (1971) conducted a series of investigations to compare predictions of the two models of motion perception. Using movie presentations, different rates, target sizes and viewing times, he concluded that the model of Kinchla and Allan was more nearly correct. Olson found that at size change rates of 3×10^{-4} rad/sec and above performance was reasonably stable and dependent upon the extent of change. For example, a 4% change was correctly identified 95% of the time at these rates and a 2% change 85-90% of the time. At rates below 3×10^{-4} rad/sec performance deteriorated steadily and seemed dependent on rate more than extent of change. These data suggest a high degree of sensitivity to the direction of change (e.g., 95% accuracy for a 4% change at 2 ft/sec at a 200 foot headway). Similar levels of sensitivity are reported by Evans and Rothery (1974) based on a field investigation.

The studies reviewed above suggest that, all other factors being equal, detection of movement in depth is easier when the approaching object is large. For example Table 3.2 compares the changes in image size over time for a car and motorcycle approaching at the same speed.

These studies have been concerned with the question of whether something is moving, without regard to direction. Another question concerns rate of movement, especially for the case where the object is moving toward or away from the observer. The research in this area, which is less well studied, has been reviewed by Hoffman (1974). It is apparent that observers have great difficulty distinguishing different rates of closure. However, there is no direct evidence to suggest that such judgments would be more difficult in the case of motorcycles than automobiles or trucks.

Complete identification of an approaching vehicle for purposes of deciding whether to attempt a maneuver requires a reasonably accurate distance estimate. Size constancy, (basically, the assumption that the apparently miniature object seen is actually a normal object at a distance) is a factor in distance judgment where the motorcycle could be at a disadvantage. Motorcycles vary in size, as do cars. But many motorcycles have fairings, and fairings vary greatly in area presented to the front, compounding the problem of estimating the actual size of the bike. The relatively low familiarity of most drivers with motorcycles, the various sizes and configurations adds to the problem. Thus, drivers may tend to err in judging the distance in an approaching motorcycle more than to an approaching car. However, there is no direct evidence that such is the case.

These data provide some reason to believe that speed-spacing decisions may be more difficult in the case of a motorcycle. If so, it may account for some of the conspicuity-related crashes.

TABLE 3-2. Retinal image size changes from a full-size automobile and motorcycle closing, head-on from 500 feet at 30 mph. (44 ft/sec.). The automobile image is measured in horizontal plane and is based on an 80" width. The motorcycle image is measured in the vertical plane and is based on a 5' height.

Elapsed Seconds	Distance	Motorcycle Image Δ Size		Full Size Automobile Image Δ Size	
		Degrees	Radians	Degrees	Radians
0	500				
1	456	.055	.001	.074	.001
2	412	.067	.001	.090	.001
3	368	.083	.001	.110	.002
4	324	.106	.002	.141	.003
5	280	.139	.002	.185	.003
6	236	.190	.003	.255	.004
7	192	.279	.005	.370	.007
8	148	.444	.008	.592	.010
9	104	.819	.015	1.092	.019
10	60	2.020	.045	2.693	.047
11	16	13.129	.230	17.507	.306

3.4 Other Driver Decision-Making about Motorcycles

We define decision-making here as the process of deciding how to react to a detected and identified motorcycle.

Information, used in the detection and identification stages, is carried forward into the decision stage. For example, the shape of the motorcycle's image tells which direction it is traveling and thereby determines, in part, if a potential conflict exists; its perceived motion indicates how fast the motorcycle is traveling with respect to the other driver and thereby provides another piece of information about the possibility of a conflict. Other driver's decisions are therefore partially based upon the same information used in the detection and identification stages.

Other drivers also use information from their memories in decisions about motorcycles. For example, drivers know by memory how much room they should allow other vehicles, including motorcycles, in executing a maneuver. Other drivers also know the difference between a motorcycle and car means that any collision with motorcycles will likely not produce much personal loss, thus possibly making them more likely to risk a collision with a motorcycle.

In general, during decision-making, drivers combine perceived information from detection and identification with remembered information. Ideally, drivers will accurately decide when a threat of a collision with a motorcycle exists and reduce that threat. Thus, other drivers should make two decisions about detected and identified motorcycles:

- Is there a threat of a conflict?
- If so, what can be done to avoid the conflict?

To determine if a conflict is possible with a detected and identified motorcycle, another driver must determine:

- If the vehicle paths will cross each other.
- If the paths will cross, whether they will cross at the same time.

Since perceiving a motorcycle's distance and speed may be difficult (see Section 3.3), determining the timing of path crossing could be more difficult for other drivers. Thus, the degraded cues for motion and speed perception provided by motorcycles can lead other drivers to err in deciding how to react.

However, even if other drivers can accurately anticipate conflicts with motorcycles, they might decide to increase the risk of a conflict because their personal loss will be less than in the case of a car.

3.5 Conclusions

The material presented in this section provides a number of possible explanations for the differences in accident trends comparing cars and motorcycles noted in Section 2.0. Clearly, the material reviewed does not indicate which of the explanations is most likely true nor does it rule out any. Furthermore, it indicates a motorcycle's "conspicuity" involves a complex series of detection, identification, and decision by the other driver. Further research may clarify these issues; in the meantime it would be best to assume that countermeasures should, as far as practical, be effective across as broad a range of possible deficiences as possible.

4.0 FIELD TEST METHODOLOGY

4.1 Introduction

The purpose of this study was to determine whether the conspicuity of motorcycles/motorcyclists could be improved in a way which would have a meaningful effect on multi-vehicle motorcycle crashes. To do this, various conspicuity-increasing treatments were fabricated and tested using a realistic driving situation which involved measuring the response of naive drivers. This section will describe how the test was carried out.

4.2 Criterion

A gap-acceptance measure was employed. The intent was to build distributions showing the probability of a car's pulling out in front of a motorcycle as a function of the distance between the motorcycle and the nearest car in front of it traveling in the same direction.

A typical situation, and the terminology which shall be used, are shown in Figure 4-1. The strategy is simple. A gap is created in the traffic stream between a lead vehicle and a test vehicle (generally a motorcycle in this study). The driver of the subject vehicle may "accept" the gap, that is merge with or cross the traffic stream, or "reject" it.

Figure 4-2 is a hypothetical distribution showing how the results of the study might appear. Basically, the probability of a gap being accepted varies as a function of its size. Changes in the conspicuity of the test motorcycle and/or rider would be expected to change the location of the distribution along the abscissa, or at least change the location of the small gap end.

This measure is useful if motorcycle crashes result at least in part from a fairly general attitude or response characteristic on the part of automobile drivers. If the problem arises from inappropriate responses on the part of a very small fraction of the driving public, then the data collection effort would become impractically large, and

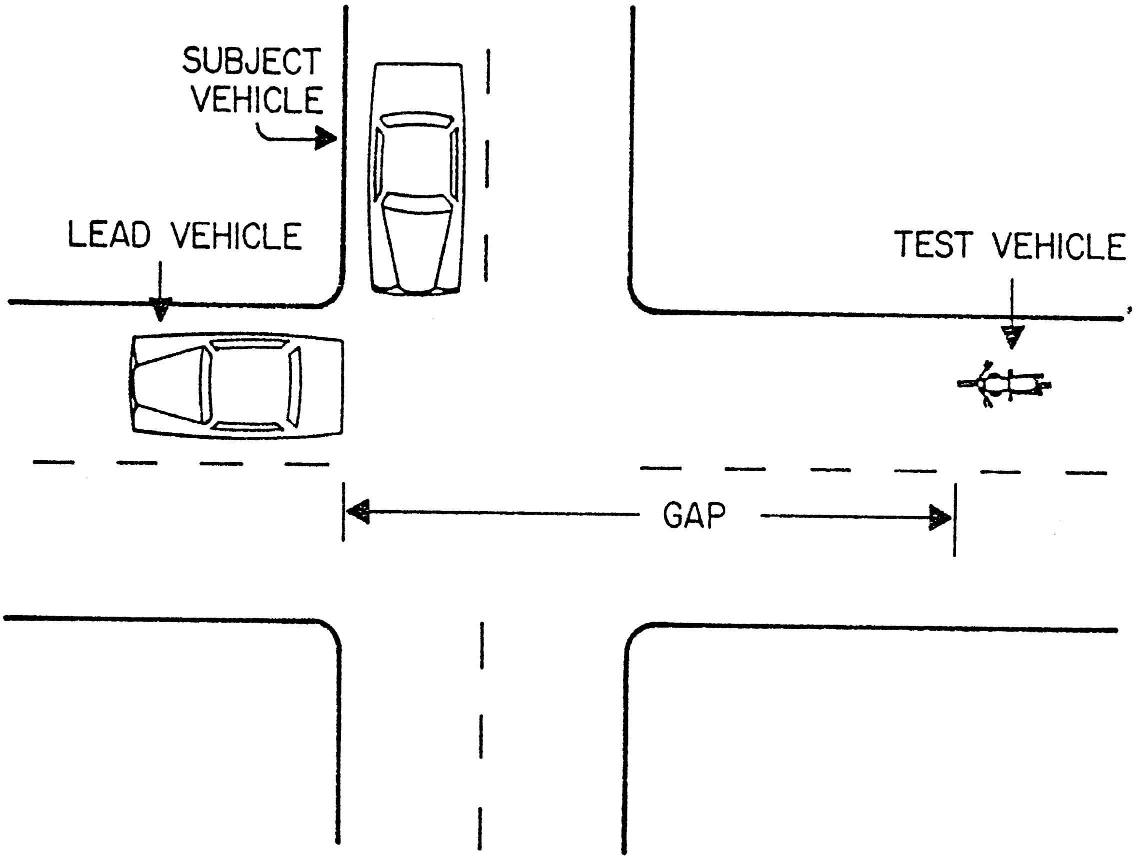

Figure 4-1. Schematic of typical gap situation employed in test.

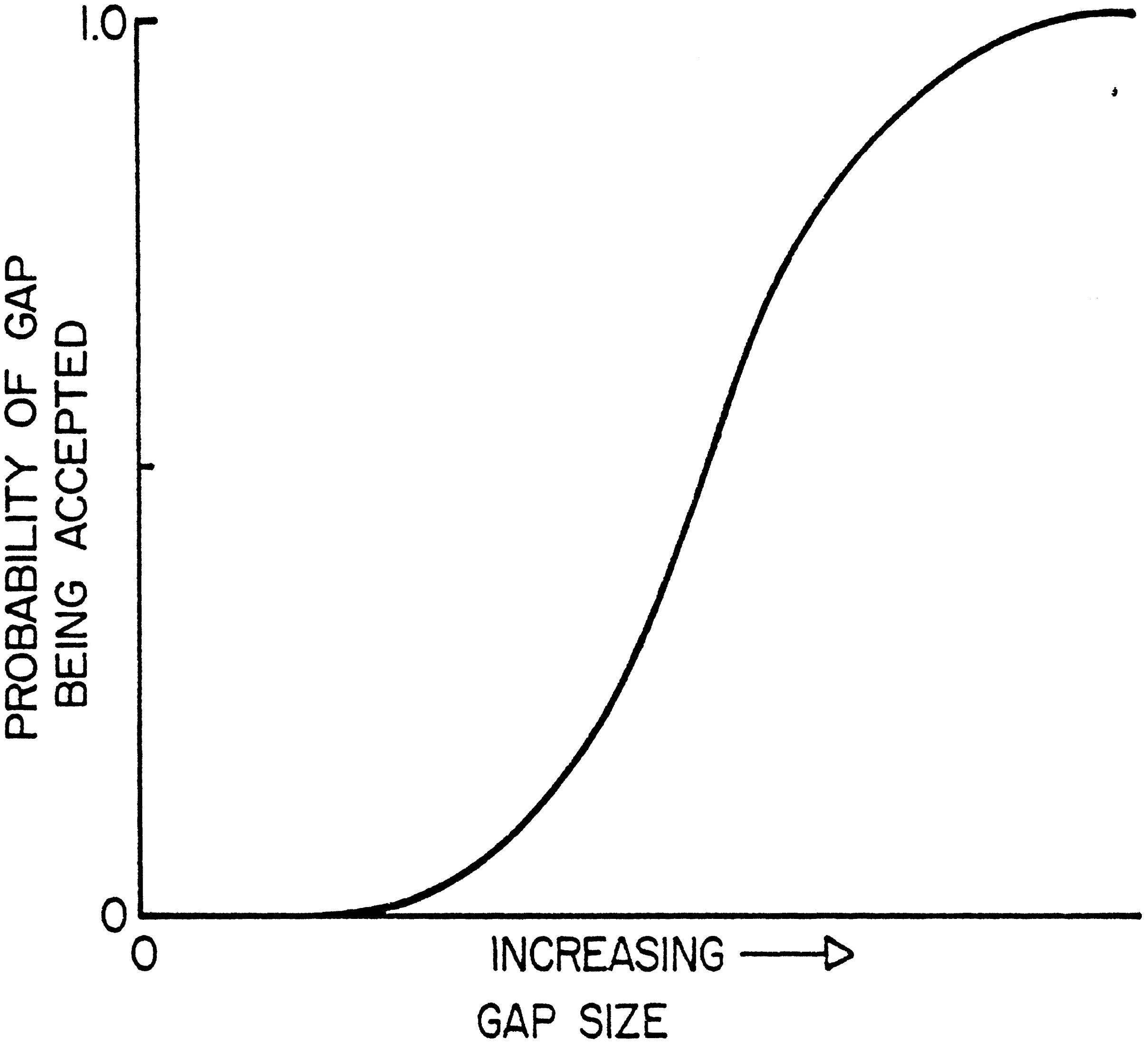

Figure 4-2. Hypothetical gap acceptance distribution.

the approach described here would not be useful.

In order to construct the required distributions it was necessary to know gap size, whether the subject vehicle accepted the gap or not, and the type of maneuver the subject driver executed or planned to execute (since the type of maneuver probably affects the gap size deemed acceptable). How this was accomplished will be described shortly.

4.3 Equipment

4.3.1 Test Treatments. The study called for testing of treatments under both day and night conditions. Some were applied to the motorcycle, others to the rider. A demonstration of more than thirty possible treatments was staged for NHTSA officials, who selected the most promising ones for test. Certain other treatments (lane position and following car) were selected to provide basic information regarding conspicuity in the absence of special treatments.

The treatments were as follows:

4.3.1.1 Motorcycle

Day:

1. Car control. A 1969 maroon Plymouth station wagon was used.
2. Motorcycle control. A normal motorcycle with no lights was used. The driver wore dark clothing and either a white or dark colored helmet.
3. Orange fluorescent fairing. The bike was equipped with a fairing to increase the frontal area. An orange fluorescent fabric was stretched over the entire fairing, including the headlight aperture. (See Figure 4-3.)
4. Green fluorescent fairing. This was the same as described above, except for the color of the fabric.
5. Headlamp on. The bike ran with low beam on.

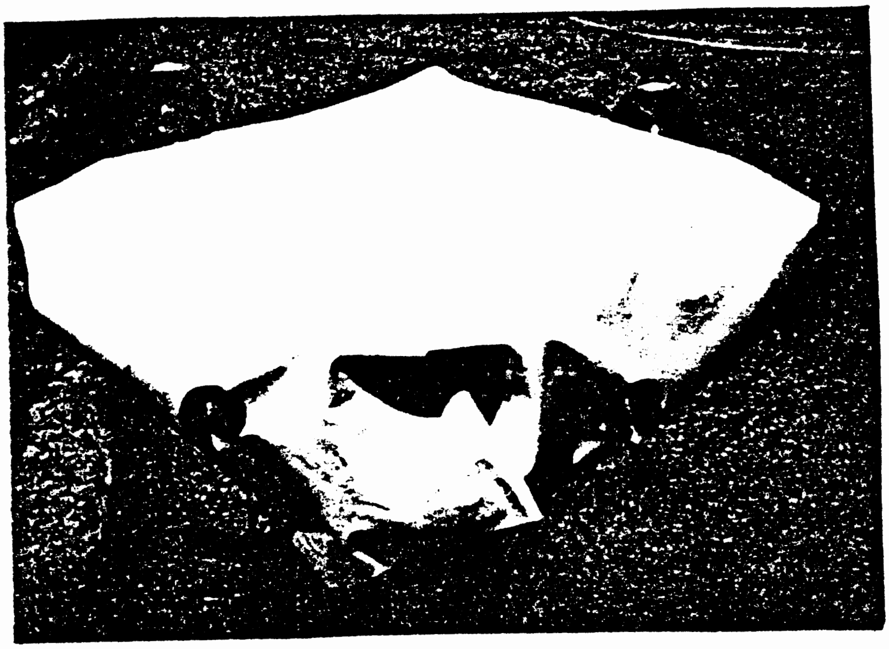

Figure 4-3. Fairing with fluorescent cover in place.

6. Modulating headlamp. The high beam filament was modulated from full to low intensity at about 3 hz. Low beam filament was off.

7. Reduced brightness headlamp. A neutral density filter reduced the intensity of the low beam to 1/10th normal.

8. Orange fluorescent outfit. The same material as used in treatment 3 was made into a vest and helmet cover to be worn by the rider.

9. Green fluorescent outfit. Same as treatment 8, using the green material.

10. Orange vest. Just the vest from treatment 8 was used.

11. Orange cap. Just the helmet cover from treatment 8 was used.

12. Following car. To test the effect a nearby car might have on the gap acceptance behavior of subject vehicles, tests were run using the station wagon described in treatment 1. It followed the bike in the same lane at 50 feet (about one second headway) in one condition and 200 feet (about 4 seconds headway) for the other condition. The motorcycle ran under control (treatment 2) conditions.

13. Lane position. All motorcycle conditions described above were run with the bike in the center of the right lane. Additional data were taken with the control bike in the left 1/3rd of the lane (left position) and the right 1/3rd of the lane (right position).

14. Combination. The best rider treatment (number 8) and bike treatment (number 6), based on test results, were combined.

<u>Night</u>:

1. Car control. The same vehicle was used as in the day condition. Low beam headlamps were used.

2. Motorcycle control. This was the same as in the day condition, except that the low beam headlamp was in use.

3. Retroreflective fairing. The fairing was covered with a retroreflective fabric, leaving the headlamp aperture open. The low beam headlamp was also on in this, as all other night treatments. The specific luminance of this material (at an entrance angle of -4^{0} and an observation angle of 0.2^{0}) was about 330 cd/ft c/ft^{2}. The material appeared white when viewed with headlamps at night. For purposes of comparison, most white retroreflective materials used in road signs have a specific luminance (new) ranging from about 100 to 250 cd/ft c/ft^{2}.

   Since a retroreflector can only work if car headlamps are directed toward it, pre-crash configurations in which the car is at right angles to the bike should not be affected.

4. Running lights. The turn signal lamps were on full time (not flashing).

5. Retroreflective outfit. The same material described in treatment 3 was used to make a vest and helmet cover.

4.3.1.2 Moped. The moped was tested only during the day. Two treatment levels were used:

1. Control. No lights or other treatments were applied to the moped. The rider wore dark clothing and no helmet.

2. Flag. Condition 1 was supplemented by a triangular orange fluorescent flag mounted on a six foot long flexible mast. This is a common bicycle accessory and was purchased at a bicycle shop.

Other motorcycle treatments were planned but no data were taken. These were as follows:

1. Wheel markers. Retroreflective tabs were attached to the wheel rim. It was intended that these would create a flashing effect to approaching vehicles. However, flicker

fusion occurred at normal operating speed and the effect was lost.

2. Motion perception aid. Note in Figure 4-4 that one of the motorcycles has an array of five lamps below the handlebars. These could be caused to flash so that the center one came on first, was extinguished, and the pair outboard of the center one came on, and were in turn extinguished with the most outboard lamps coming on. This cycle was repeated at about 0.5 hz. The idea was to provide a display which made the bike appear to grow larger (hence be approaching faster) than it actually was. However, when used in trials the system was apparently confused with an emergency vehicle so that lead vehicles pulled to the side of the road.

4.3.2 Vehicles. Two motorcycles were used in the data collection stage. Both were donated by Honda Motor Company. One was a 1974 350 cc 4 cylinder and the other was a 1976 400 cc 4 cylinder. The two bikes are shown in Figure 4-4.

The moped was a 1973 Ciao. It was typical of mopeds in general and had a top speed of about 25 mph.

4.3.3 Instrumentation. The instrumentation requirements for this project posed rather substantial limitations in that size, weight and power consumption had to be kept to a minimum. At the same time, the equipment had to be accurate and easy to operate. Finally, since thousands of individual trials were to be collected, data reduction had to be effected in an economical manner. As finally developed, the equipment met these demands very well.

The equipment carried on the motorcycles consisted of units which generated, conditioned and stored signals. Distance traveled was measured by means of a magnetic sensor mounted on the chain guard as shown in Figure 4-5. Two metal markers attached to the wheel triggered

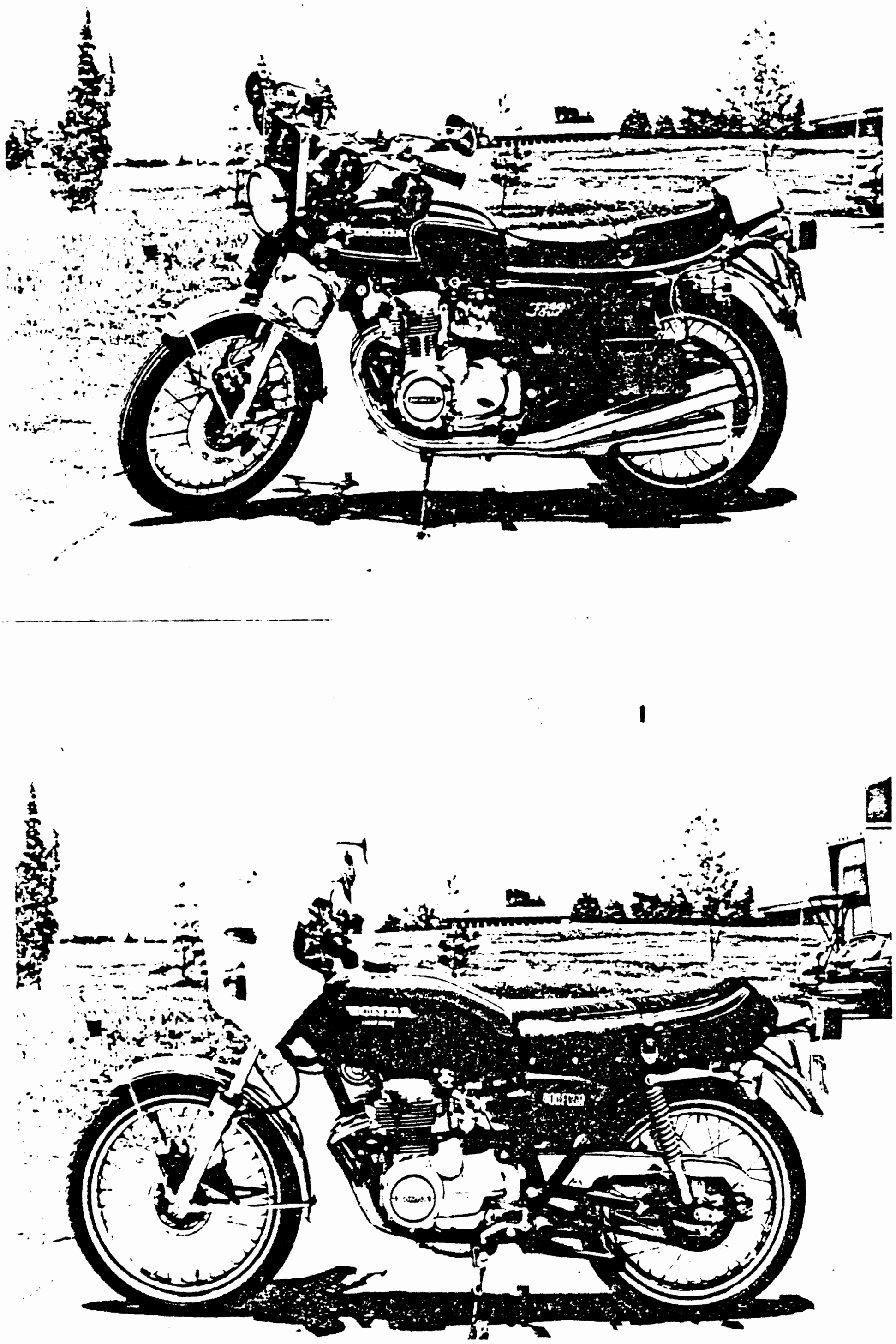

Figure 4-4. Motorcycles used in test program.

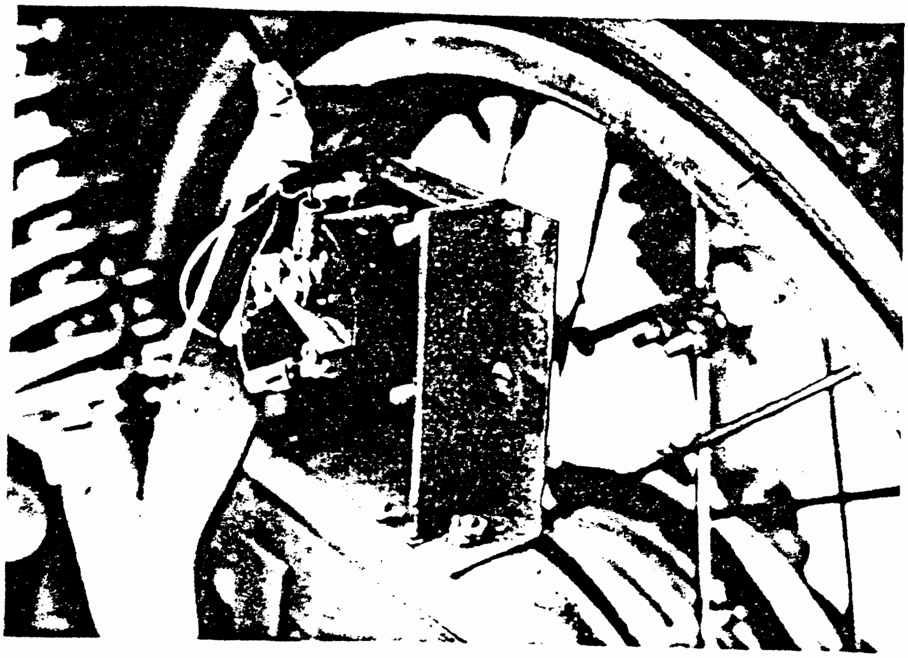

Figure 4-5. Magnetic sensor and wheel marker.

the sensor and produced a signal which, when conditioned, resulted in a spike of fixed duration and amplitude. Since the wheel traveled 75 inches per revolution, each spike occurred at 37.5 inches. Event markers in the form of push buttons were mounted on or near the handlebars for easy access by the rider (see Figure 4-6). Pressing any of these buttons converted the next wheel pulse into a spike having a distinctive amplitude (eight levels were possible).

The events of interest were:

1. The start and end of a gap.
2. Whether the subject vehicle accepted the gap.
3. The type of maneuver the subject driver executed or planned to execute.

Data were collected as follows:

The test rider sought to position the motorcycle to the rear of a group of cars and open a gap between the rearmost car (lead vehicle) and the test motorcycle sufficient to produce a reasonable likelihood of acceptance by vehicles seeking to execute maneuvers of the type of interest. There were three such maneuvers. These are described below and illustrated in Figure 4-7.

1. The subject vehicle is on the right of the test vehicle and its driver is seeking to cross the road completely or turn left and go in the opposite direction. This shall be referred to as "right - cross or left turn."
2. The subject vehicle is on the right of the test vehicle and its driver is seeking to turn right and go in the same direction. This shall be referred to as "right - right turn."
3. The subject vehicle is in the center of the road, facing toward the test vehicle and its driver is seeking to make a left turn across the path of the test vehicle. This shall be referred to as "center - left turn."

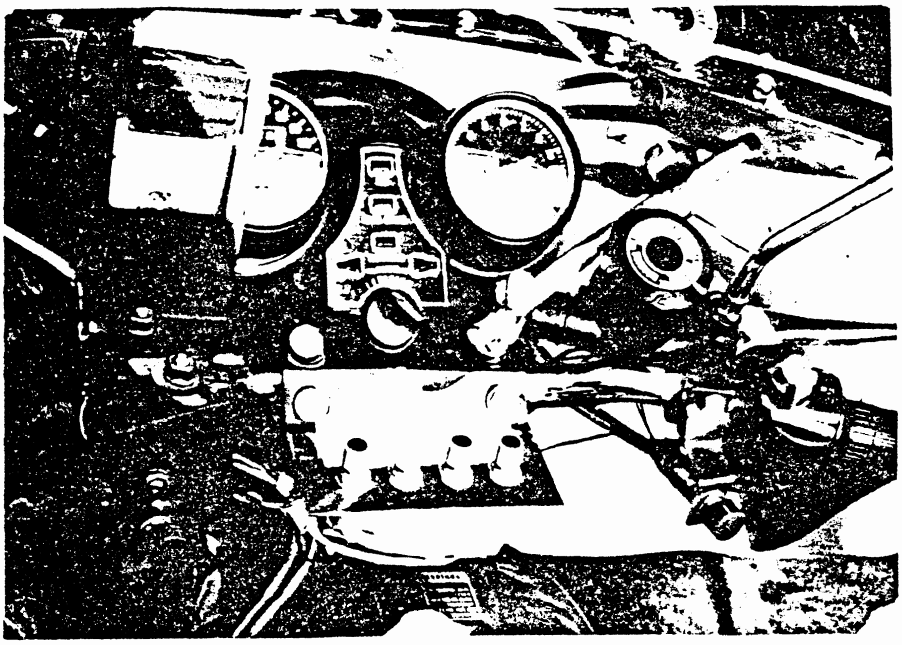

Figure 4-6. Photograph of controls area, showing push-buttons used for coding data.

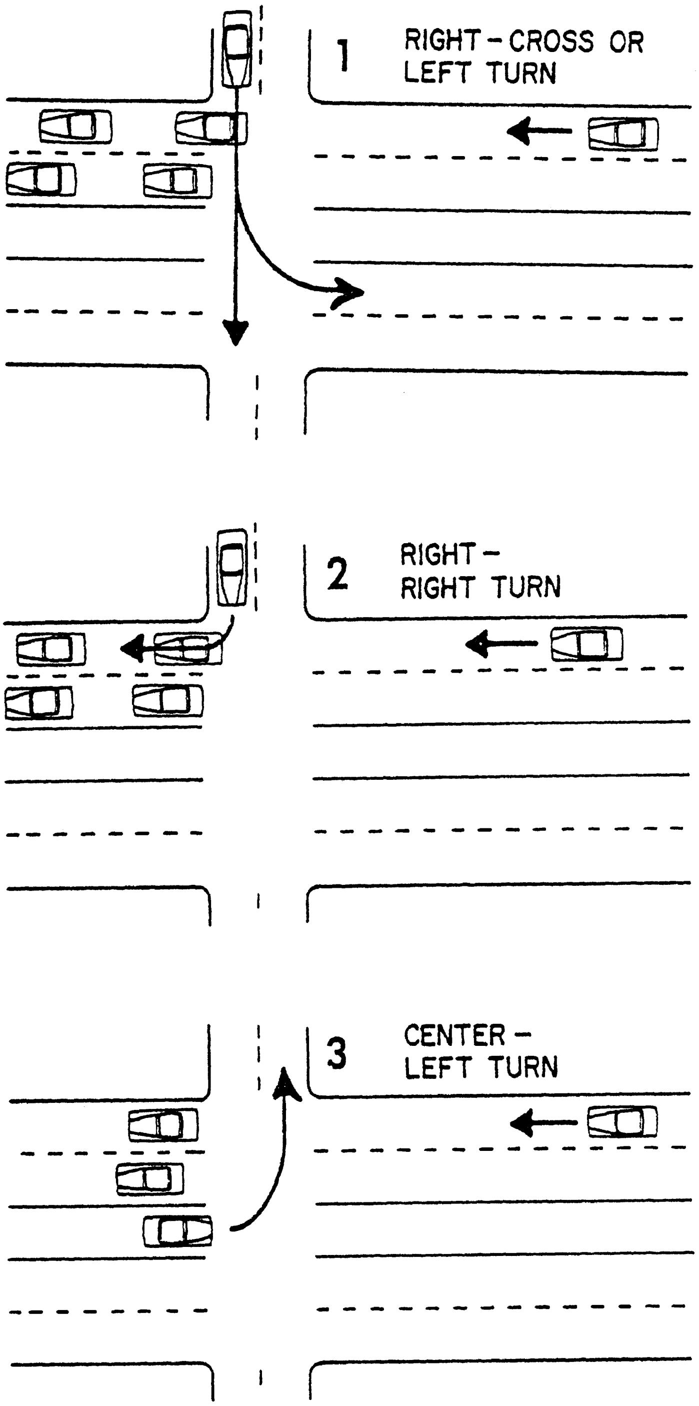

Figure 4-7. Schematics of the three maneuvers investigated in the present study.

The test riders were instructed that when the lead vehicle passed a subject vehicle standing in either of the positions shown in Figure 4-7, they should press the "1" button located near the left handgrip. This marked the start of the gap. If the subject driver accepted the gap, the rider pressed the "2" button located near the right handgrip as soon as the subject vehicle began to move. Then the rider pressed the "2" button again while passing the point where the subject vehicle was or had been standing to mark the end of the gap. All that remained at this time was to press one of three buttons located just below the speedometer to indicate the type of maneuver. These data were recorded on a small cassette audio recorder which was carried on the rear of the saddle as shown in Figure 4-8.

The resultant records appeared as shown in Figure 4-9. The top tracing is an example of a gap which was accepted. The small marks are from the wheel pulsor, each one representing about three feet of travel. The gap first became available to the subject driver at the point marked by the 1 pulse, and the motorcycle passed the place where the vehicle had been located at the point marked by the second 2 pulse. Acceptance is indicated by the presence of two 2 pulses. The code pulse (c) indicates that this was a type 3 maneuver (center - left turn) as described in Figure 4-7. Gap size is determined by counting the number of wheel pulses intervening between the 1 and second 2 pulse and multiplying by 37.5 inches.

The lower trace is an example of a rejected gap. In this case the maneuver was a type 2 (right - right turn) as described in Figure 4-7.

The accuracy of the system was checked in three different ways. First the bike was walked through a series of measured intervals. It was then ridden at 40 mph with the motorcyclist pressing the 1 and 2 buttons while passing markers set at known intervals. Some data were then collected along with an independent written record of the rough gap size (large, medium or small) and type of maneuver to verify that the computer data processing system yielded the same results.

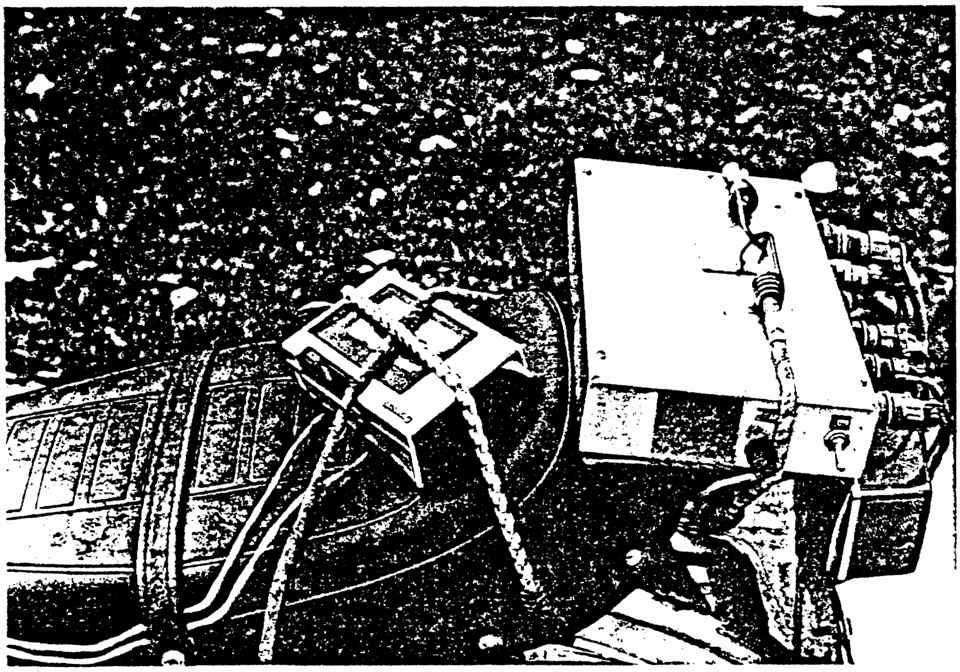

Figure 4-8. Rear of motorcycle saddle, showing recorder in position.

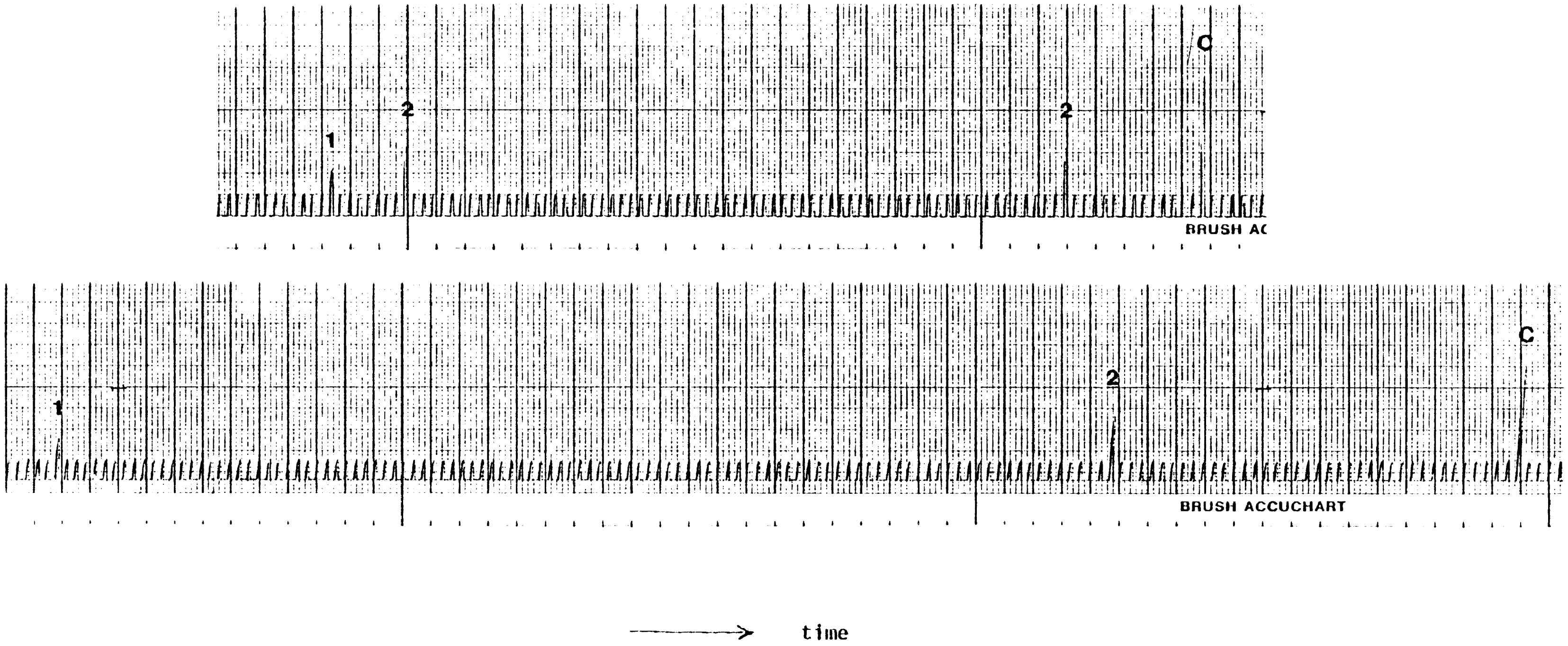

Figure 4-9. Sample data traces.

The system described worked very well, although it required regular maintenance and occasional repair. Because much of the night data were collected at a point remote from HSRI, a system was developed which required less maintenance.

In this system the sensor drove a digital counter, which was mounted over the bike speedometer. Pressing the "1" button reset and started the pulse counter and a timer mounted next to it. When the rider passed the subject vehicle position he pressed the button again to stop the counters. The information on the counters, together with the maneuver and accept-reject data were recorded verbally on a small tape recorder.

The main advantage to this system was freedom from maintenance. Data reduction was a slow, manual process however.

4.3.4 Test site. A site was sought which had a high volume of vehicles attempting the maneuvers of interest. A reasonable volume of parallel traffic was required as well, to provide lead vehicles for the front end of the gap. The site used for the day data collection is a major thoroughfare connecting the two cities of Ann Arbor and Ypsilanti, Michigan. In terms of data points per hour, it seemed far the best site of those explored. It is five lanes wide (center lane for left turns) and lined for much of its length with small businesses of various kinds. Speed limits were 45 mph for about 3/4ths of the four-mile length, 35 mph for the rest. There are three stop lights in the test section.

Most night data were collected during the winter months in the city of Gainesville, Florida. A major thoroughfare having many of the characteristics of the northern site was used. Data taken on the same configurations in both sites did not differ statistically.

There were some difficulties with both motorcycle sites. Briefly, these were as follows:

1. Data could not be taken on vehicles attempting to merge or cross from the left side of the street. Due to the width

of the street, vehicles making a left merge from the left side would not have been affected by a single vehicle in the far right lane. Full crossing maneuvers rarely occurred except at signalized intersections. Thus, the "right-cross or left turn" maneuver was almost always a "right - left turn."

2. It was easily possible for other vehicles to pass the test vehicle. This made it more difficult to take data, especially in heavy traffic. It also required the test rider to closely monitor traffic behind him, to be certain that he was sufficiently isolated so that subject drivers would be responding only to the test vehicle. It will be recalled that one of the conditions ("following car") offered an opportunity to examine this effect. The results, as will be noted shortly, provide reason to believe that the presence of a car close to the motorcycle might have an effect on the response of merging drivers.

3. There were questions concerning the gap start point for some maneuvers. For example, if the rearmost car of the group leading the motorcycle was in the left lane, what effect would this have on a driver making a right-right turn maneuver (type 2 in Figure 4-7)? No definite answer can be provided. Data were taken with the rearmost car in either lane under the assumption that differences, if any, would apply equally to all conditions. It was also difficult to judge the effect of opposing traffic on drivers attempting right-left turn maneuvers (type 1 maneuvers in Figure 7). When facing traffic from the right, most drivers first turned into the left turn lane, then merged right when the opportunity presented itself. Some drivers may have waited until there was an adequate gap in both directions. The simplest solution was to take data as though there was no oncoming traffic and assume that differences would be distributed equally over all conditions.

Finding a test site for the moped was very difficult. Because its speed capabilities were so limited, data could not be taken at the motorcycle site. An attempt was made to use some secondary roads in the area, but the traffic volumes were too low to provide adequate data. The test was finally set up at a shopping mall. The moped circled the mall on the interior road, closest to the buildings (a route about two miles long) and data were taken on cars moving in and out of the parking lots.

4.4 Data Reduction Procedure

Data reduction was completed in three phases. A computer program, called PULDIG, digitized the analog signals. The signals corresponded to the "blips" illustrated in Figure 4-9. PULDIG translated the blips, made by the motorcycle's wheel pulses and buttons, into numbers. The size of the number corresponded to the height of the blip. Since the pulser and different buttons produced blips of different heights, PULDIG's numbers coded the series of wheel pulses and button pulses.

In the second phase, a second computer program, called AUTRED, identified trials from the series of PULDIG-coded numbers, computed the time and distance gaps of each trial, and coded the maneuver performed by the subject vehicle. AUTRED identified trials by looking for series of PULDIG codes beginning with a No. 1 button push followed by one or two No. 2 button push(es) interspersed with wheel pulses and ending with a maneuver code. AUTRED also identified nonsensical series of PULDIG numbers to provide the experimenters with feedback on the performance of the motorcycles and instrumentation. As AUTRED looked for trials, it counted the distance and time between button pushes. The calculations were based on the wheel pulses. AUTRED coded the maneuver based on the numbers representing the button pushes.

Table 4-1 presents the coding functions used to translate motorcyclist and instrument actions into numbers for the computer programs. The columns represent possible actions by the motorcycle instrumentation (wheel pulses) and experimenter-motorcyclist (button pushes).

TABLE 4-1. Coding functions for translating data from motorcyclist's action to trial codes.

	EXPERIMENT ACTION					
Translation	Wheel Pulse	#1 Button Push	#2 Button Push	#3 Button Push	#4 Button Push	#5 Button Push
Meaning in experiment	Motorcycle had traveled another 37.5 inches	A potential maneuver gap had just opened	Either subject vehicle began maneuver, or motorcycle passed initial vehicle location	Right-cross or left turn	Right-right turn	Center-left turn
Voltage of blip on analog tape	1	2	3	4	5	6
PULDIG code number	51-150	151-250	251-350	351-450	451-550	551-650
Meaning to AUTRED	Increment time and distance counters	New trial begins	Maneuver beginning marker; trial completion marker	Maneuver Code 1	Maneuver Code 2	Manuever Code 3

The first row describes what meaning this action had in the experiment. The second row indicates the voltage (height) of the blip put on the tape by each action (see Figure 4-9 for examples). The third row shows PULDIG code ranges for the voltages. The ranges are much larger than those PULDIG actually put out; in general, PULDIG put out numbers which were the voltages multiplied by 100. The fourth row lists each code's meaning to AUTRED; AUTRED relied upon this information to identify trials.

In the third and final phase of data reduction, a senior experimenter transcribed the time and distance gaps of each trial onto data-coding sheets. The experimenter recorded counts of the gaps which fell in different intervals, and whether they were accepted or rejected. The transcription phase allowed senior staff to constantly monitor data quality. The experimenter discarded the few (less than 1%) nonsensical trials during transcription.

In sum, the three phases of data reduction translated the wheel pulse/button push records into frequency distributions of time and distance gaps. Constant quality control by senior staff ensured the data were reliable and accurate.

As noted, both time and distance data were taken. Both forms showed the same results; however, the distance data were noisier than the time data. Therefore, the time data were used in the full analysis reported here.

4.5 Data Analysis Procedure

The purpose of the statistical analyses was to determine which conspicuity treatments--in comparison to a no-treatment control condition--served to reduce the acceptance rate of small gaps. Two separate statistical procedures were utilized: (1) probit analysis, and (2) rejected-gap analysis. These analyses serve to corroborate one another.

The probit analysis technique (e.g., Finney, 1971) is specifically designed to deal with population response frequencies at varying levels of an independent variable. The basic data in this study are the numbers of motorists accepting or rejecting gaps of various sizes. In theory every motorist has a threshold gap size in a given situation. Beneath this threshold the gap will be rejected, above it the gap will be accepted. It was anticipated that the gap thresholds for a population of motorists would be approximately normally distributed across a logarithmic transformation of the gap sizes. If the exact normal distribution were known, it would be possible to predict the population acceptance rate for any gap size. It is the goal of the probit analysis to fit the best normal distribution to the data.

Since the probit analysis requires frequencies at specific gap sizes, the data were tabulated into 2 by 10 frequency tables, one for each maneuver and treatment. The two rows of the tables referred to accepted and rejected gaps respectively, the ten columns referred to gap size midpoints, in seconds, ranging from 1 to 10. These tables were then supplied as input to an iterative probit computer program capable of fitting a normal distribution to data within a specified error tolerance. The output for each treatment was a linear regression function: normal standard deviates as predicted by (logarithmic) gap sizes. Thus, for any specified gap size, the treatments can be ranked by simply comparing the predicted proportions of motorist responding.

There is one aspect of the probit analysis technique which presents potential difficulty with regard to these data. A normal distribution can be best predicted when most of the data fall near the middle of the distribution. This study necessarily emphasized data collection at small gap sizes--where less than 50% of the population of motorists respond. It is therefore appropriate to verify the probit analysis results with a technique that is less sensitive to emphasis at particular gap sizes. The second analysis was based on the probability that the subject drivers would reject gaps of various sizes. It will be referred to as a "Rejected Gap Analysis."

In most cases the two forms of analysis agree. Where they do not, interpretations are based on the rejected gap analysis, due to the possible problem with probit mentioned above.

5.0 RESULTS AND DISCUSSION

The results of both the probit and rejected gap analyses are presented in this section. The various conspicuity treatments are separated depending on whether they were intended for day or night use. Car-following, lane-position, and the moped results, follow the main analyses.

It will be recalled that measurements were made on three maneuvers of the subject vehicle. The results from the three maneuvers differ, so each treatment or class of treatments is considered separately under each of the maneuvers.

5.1 Daytime Treatments

5.1.1 Right - Cross or Left Turn. Figure 5.1 is a diagram of this maneuver. Of the three maneuvers, this was probably the most difficult for the subject motorist, since he/she must be concerned with traffic from two directions.

Figure 5-2 plots the probit regression curves for the conspicuity treatments, and motorcycle and automobile controls. Values on the ordinate are proportional to the probability of gap acceptance, so the lower the point of intercept, the lower the probability of short gaps being accepted, and the better the treatment. These data indicate that there was a higher probability of subject drivers accepting smaller gaps when confronted with the control motorcycle and dimmed headlamp conditions. The rest of the conditions were associated with a diminished likelihood of accepting small gaps.

Table 5-1 presents the rejected gaps analysis for the right-cross or left turn maneuver. Three analyses are shown. The leftmost is for gaps up to and including three seconds. The second analysis includes the totals from the first and adds gaps up to and including four seconds. Gaps up to and including five seconds are added in the last analysis. Data for the control motorcycle are provided at the top of

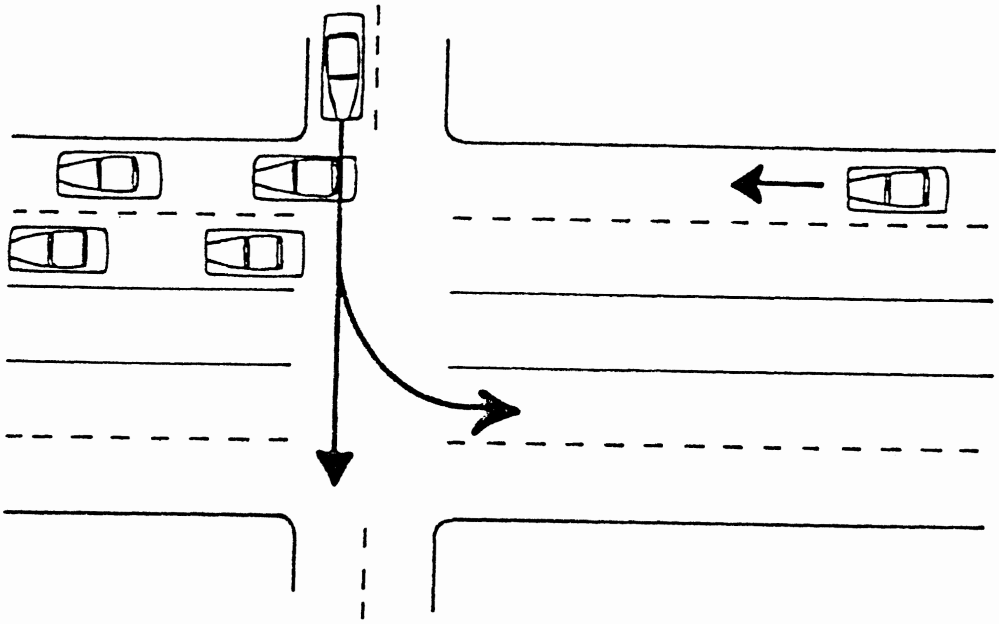

Figure 5-1. Diagram of a right - cross or left turn maneuver.

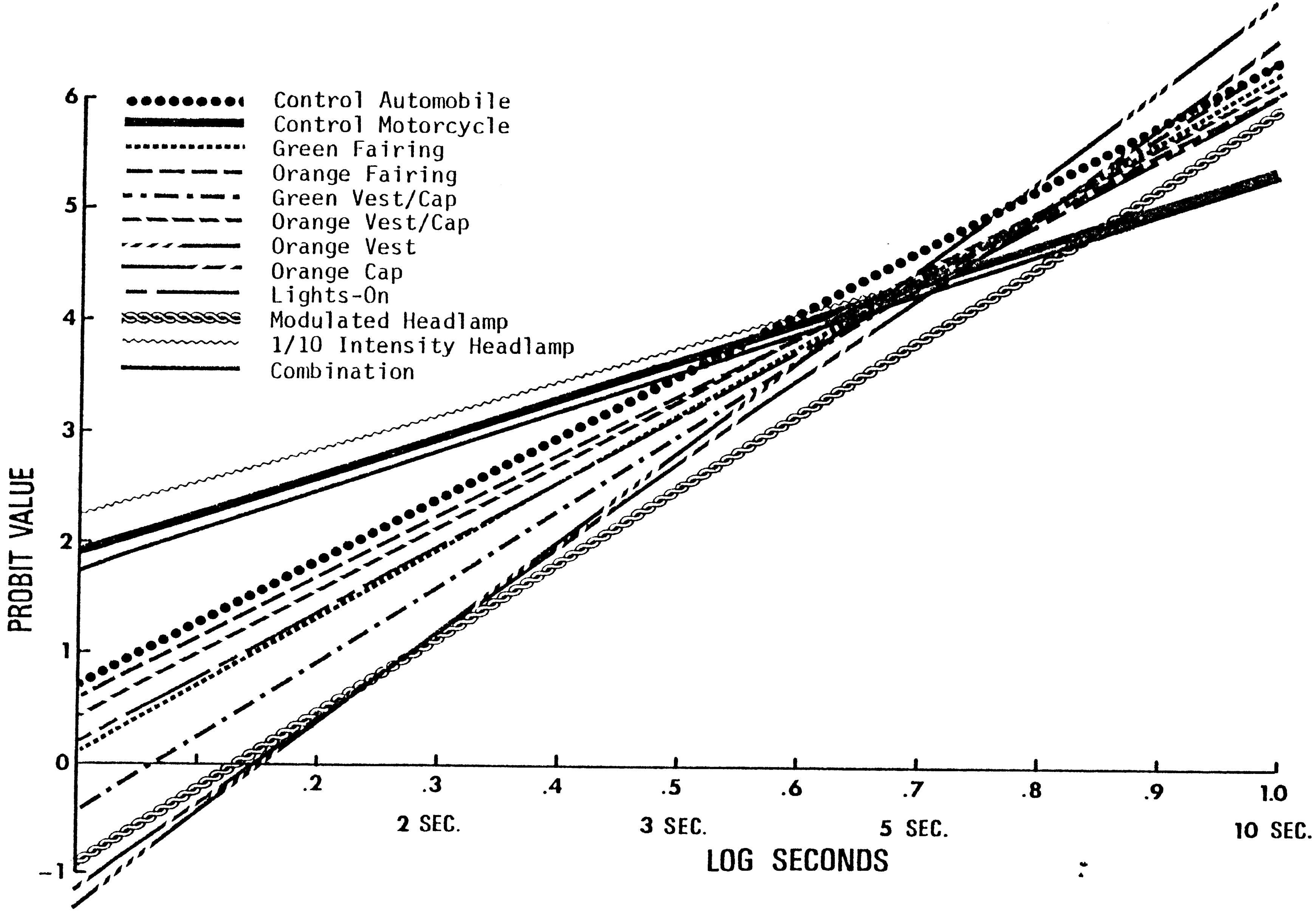

Figure 5-2. Probit results for daytime conditions--right - cross or left turn maneuver.

TABLE 5-1. Rejected-gap analysis for right - cross or left turn maneuvers--daytime conditions.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Motorcycle: N = 189, P = .94				Control Motorcycle: N = 281, P = .92				Control Motorcycle: N = 338, P = .90			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Automobile Control	57	.97	-.03	-.89	119	.92	0	0	165	.89	.01	.35
Orange Fairing	122	.98	-.04	-1.67*	190	.94	-.02	-.82	282	.88	.02	.80
Green Fairing	120	.98	-.04	-1.66*	193	.96	-.04	-1.75*	229	.92	-.02	-.81
Orange Vest/Cap	144	.99	-.05	-2.35**	229	.96	-.04	-1.86*	299	.90	0	0
Green Vest/Cap	103	1.00	-.06	-2.54**	176	.97	-.05	-2.18*	241	.90	0	0
Orange Vest	74	.99	-.05	-1.74**	103	.98	-.06	-2.13*	124	.94	-.04	-1.34#
Orange Cap	157	1.00	-.06	-3.12**	234	.97	-.05	-2.43**	276	.93	-.03	-1.32#
Lights-on	234	.99	-.05	-2.89**	327	.97	-.05	-2.74**	338	.92	-.02	-.94
Modulated Headlamp	134	.99	-.05	-2.28*	241	.99	-.07	-3.74**	306	.97	-.07	-3.55**
Dimmed Headlamp	97	.99	-.05	-1.50#	194	.85	.07	2.41	247	.84	.06	2.16
Combination	54	.96	-.02	-.57	86	.90	.02	.58	88	.90	0	0

# indicates .1 level of significance (one-way), * indicates .05 and ** indicates .01.

each group of columns. The meaning of the column headings is as follows:

N = number of subject vehicles included.

P = percentage of subject vehicles rejecting the gap.

P_{diff} = P for control motorcycle minus P for the treatment condition.

Z = Z score, on which statistical differences are estimated.

The treatments are grouped within the table as follows:

Automobile control

High visibility materials applied to the bike

High visibility materials worn by the rider

Lighting treatments

Combination

In general, the rejected gap analysis shows the same trends as the probit analysis. For gaps of three seconds or less, any of the tested treatments are better than the control motorcycle. The dimmed headlamp, combination, and automobile control are not statistically different, however.

The situation changes as larger gaps are considered. Nominally, this is of little concern, since the function of the treatments is to protect against acceptance of very short gaps. However, it is interesting to note the continued effect of the modulated headlamp even at gaps as large as five seconds. This may represent a novelty effect. If so, it would be expected to diminish were the treatment to be commonly employed.

5.1.2 Center - Left Turn. Figure 5-3 is a diagram of the center-left turn maneuver.

Figure 5-4 plots the probit regression lines for the maneuver. Two groups appear to be divided by the automobile control within the

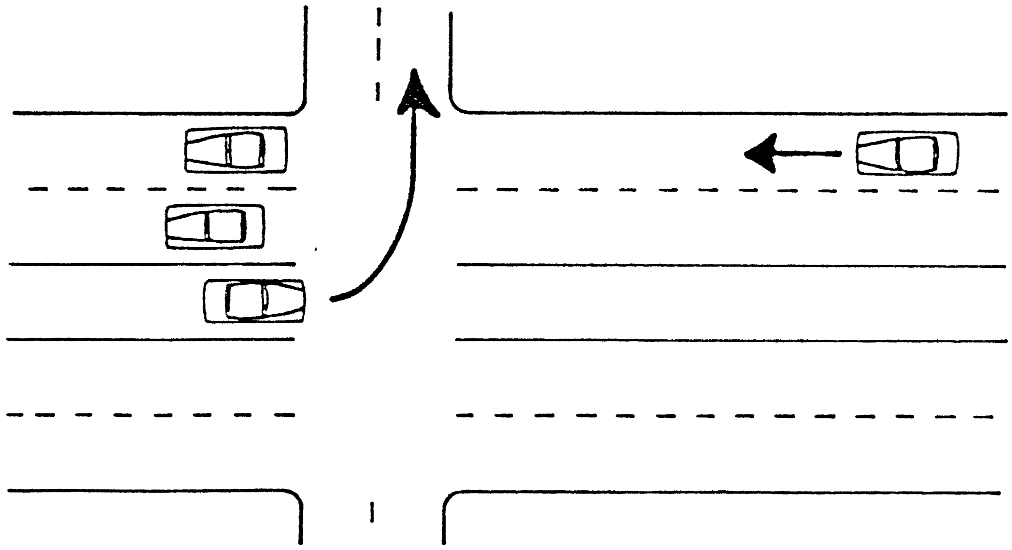

Figure 5-3. Diagram of a center - left turn maneuver.

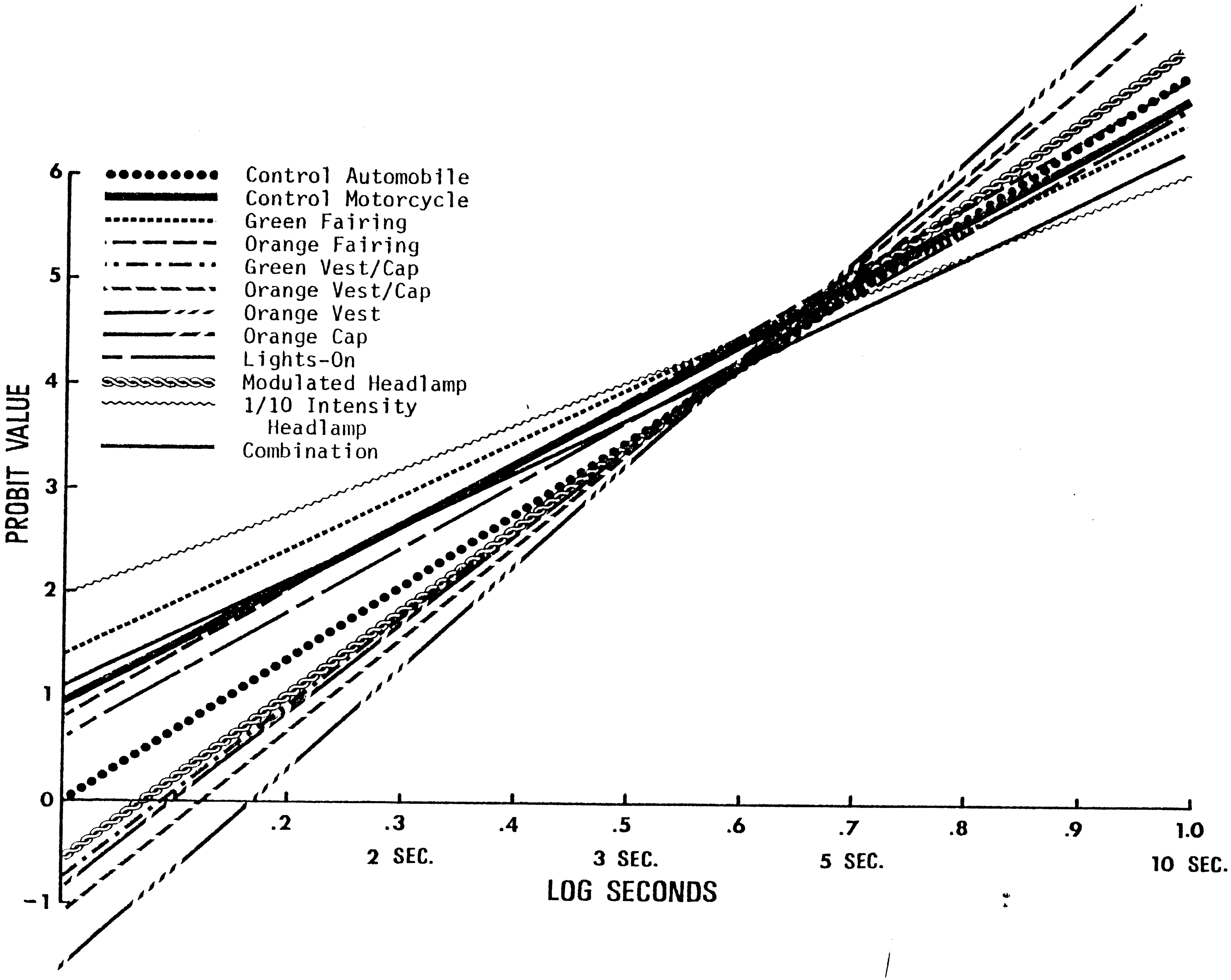

Figure 5-4. Probit results for daytime conditions--center - left turn maneuver.

graph. The control motorcycle, dimmed headlamp, lights-on, and treated fairings bunch together with relatively poor performance in the small gap region. In comparison, motorcyclist garments and the modulating headlamp show relatively good performance. The automobile control probit falls in between the two clusters, but closer to the most effective conditions.

Table 5-2 presents the rejected gap analysis for this maneuver. In general, the results compare well with those for the right-cross or left turn maneuver. The differences tend not to be as large for this maneuver, and there are fewer statistically significant differences at the smaller gaps. Interestingly, the differences between test and control conditions become more pronounced as larger gaps are included in the analysis. This may represent a novelty effect; however, the performance of the headlamp on condition argues against this interpretaion. (Although Michigan does not have a lights-on law, many motorcyclists ride with lights on in daytime. Thus the subject drivers should have been used to seeing motorcycles with lights on.)

5.1.3 Right-Right Turn. From the point of view of the subject driver, this is probably the simplest of the three maneuvers. It is diagrammed in Figure 5-5.

Figure 5-6 presents the probit traces for the conspicuity treatments in the right-right turn maneuver. No clear-cut pattern or profile is evident in that graph, compared with the previous probit graphs.

Table 5-3 presents the rejected gap analysis for the right-right turn maneuver. The probabilities appear much different than for the other two maneuvers. There are a few statistically significant differences, but these are not consistent and, as a matter of fact, occur about as often as would be expected based on chance.

Overall, both the probit and rejected gap analyses provide no strong indication that any condition is different from the motorcycle control on the right-right turn maneuver. The apparent reason for the

TABLE 5-2. Rejected-gap analysis for center - left turn maneuver--daytime conditions.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Motorcycle: N = 168, P = .95				Control Motorcycle: N = 266, P = .86				Control Motorcycle: N = 348, P = .77			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Automobile Control	151	.95	0	0	259	.88	-.02	-.68	334	.82	-.05	-1.62#
Orange Fairing	223	.93	-.02	.82	356	.86	0	0	438	.79	-.02	-.67
Green Fairing	105	.95	0	0	152	.90	-.04	-1.19	183	.81	-.04	-1.06
Orange Vest/Cap	215	.98	-.03	-1.63*	356	.91	-.05	-1.96*	481	.81	-.04	-1.4#
Green Vest/Cap	204	.97	-.02	-.99	283	.90	-.04	-1.44#	331	.84	-.07	-2.30*
Orange Vest	97	.99	-.04	-1.70*	130	.95	-.09	-2.68**	159	.86	-.09	-2.34**
Orange Cap	151	.97	-.02	-.90	189	.94	-.08	-2.72**	212	.88	-.11	-3.23**
Lights-on	382	.97	-.02	-1.16	482	.93	-.07	-3.13**	547	.87	-.10	-3.89**
Modulating Headlamp	122	.98	-.03	-1.33#	216	.90	-.04	-1.33#	285	.82	-.05	-1.54#
Dimmed Headlamp	84	.89	.06	1.76	143	.87	-.01	.28	177	.79	-.02	-.52
Combination	132	.96	-.01	-.41	187	.91	-.05	-1.62#	192	.91	-.14	-4.05**

# indicates .1 level of significance (one-way), * indicates .05, and ** indicates .01.

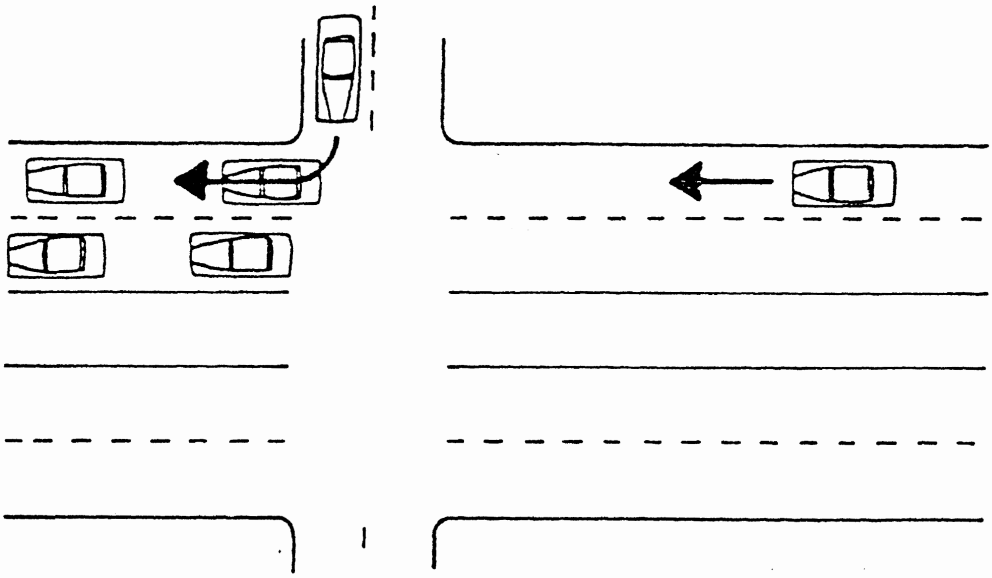

Figure 5-5. Diagram of a right - right turn maneuver.

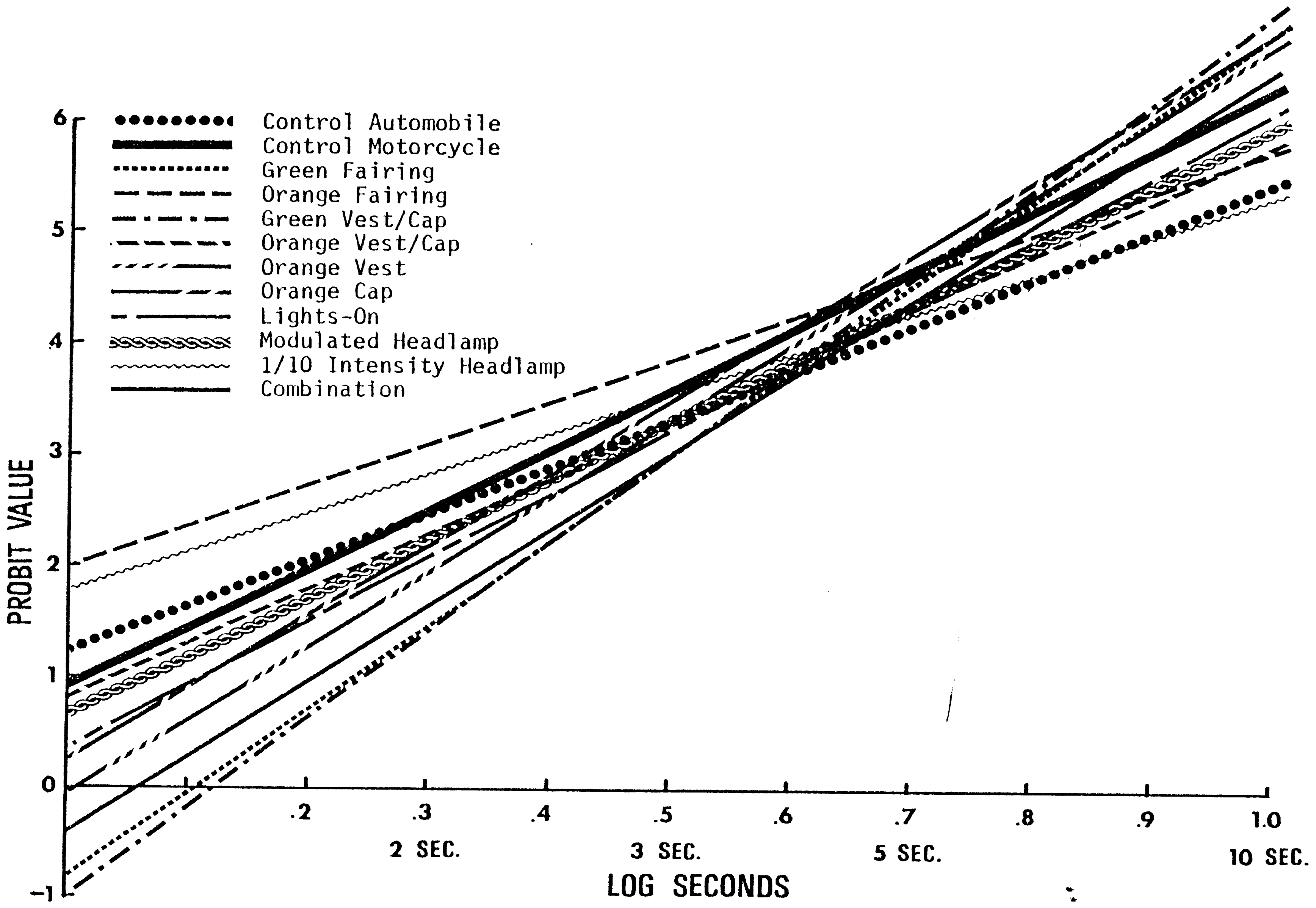

Figure 5-6. Probit results for daytime conditions--right - right turn maneuver.

TABLE 5-3. Rejected-gap analysis for right - right turn maneuver--daytime conditions.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Motorcycle: N = 167, P = .98				Control Motorcycle: N = 248, P = .93				Control Motorcycle: N = 293, P = .88			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Automobile Control	152	.97	.01	.57	248	.95	-.02	-.94	325	.93	-.05	-2.13*
Orange Fairing	150	.95	.03	1.47	214	.90	.03	1.16	276	.86	.02	-.71
Green Fairing	158	.98	0	0	241	.97	-.04	-2.02*	299	.91	-.03	-1.19
Orange Vest/Cap	184	.97	.01	.60	261	.95	-.02	-.95	335	.90	-.02	-.80
Green Vest/Cap	122	.99	-.01	-.67	207	.94	-.01	-.24	274	.86	.02	.71
Orange Vest	55	.98	0	0	79	.92	.01	.30	87	.90	-.02	-.51
Orange Cap	147	.97	.01	.57	192	.94	-.01	-.42	216	.90	-.02	-.71
Lights-On	260	.99	-.01	-.86	339	.96	-.03	-1.61#	402	.89	-.01	-.41
Modulated Headlamp	84	.98	0	0	174	.94	-.01	-.41	221	.92	-.04	-1.49#
Dimmed Headlamp	103	.95	.03	1.37	188	.92	.01	.39	216	.91	-.03	-1.08
Combination	104	.97	.01	.52	161	.98	-.05	-2.26*	165	.97	-.09	-3.27**

# indicates .1 level of significance (one-way), * indicates .05 and ** indicates .01.

lack of differences is the very high probability of short gaps by the control bike being rejected (0.98), leaving little room for improvement. Why the subject drivers behaved more cautiously on this maneuver than on the other two is not clear, although it may arise from the fact that this maneuver places one in the path of an approaching vehicle much longer than the other two.

Interestingly, the right-right turn maneuver corresponds to the maneuver studied by Kirkby & Stroud (1978) in their use of the gap acceptance methodology. They failed to find significant differences as well.

5.1.4 Summary, Daytime Treatments. These data suggest that the daytime conspicuity of motorcycles can be improved in several ways having a meaningful effect on the drivers of automobiles. Riding with the headlamp on seems very effective, although causing the headlamp to modulate from low to high intensity seems to improve response even more. The wearing of fluorescent materials also seems effective. However, applying the same materials to the motorcycle has a less pronounced effect, especially for the center-left turn maneuver.

5.2 Nighttime Treatments

5.2.1 Right-Cross or Left Turn. Figure 5-7 shows the probit fits for each of the nighttime conditions. The profiles are all similar except for the running lights condition. Running lights appear to be somewhat more effective than the other conditions.

Table 5-4 presents the rejected gap analysis for the nighttime conditions. Only the running lights treatment appears to offer consistent improvement relative to the control bike. However, because the subject vehicle is initially at right angles to the approaching test vehicle, retroreflective treatments would not be expected to be effective.

5.2.2 Center-Left Turn. Figure 5-8 presents the probit fits for this maneuver. The differences are not large; however, the retroreflective treatments appear somewhat better than the control.

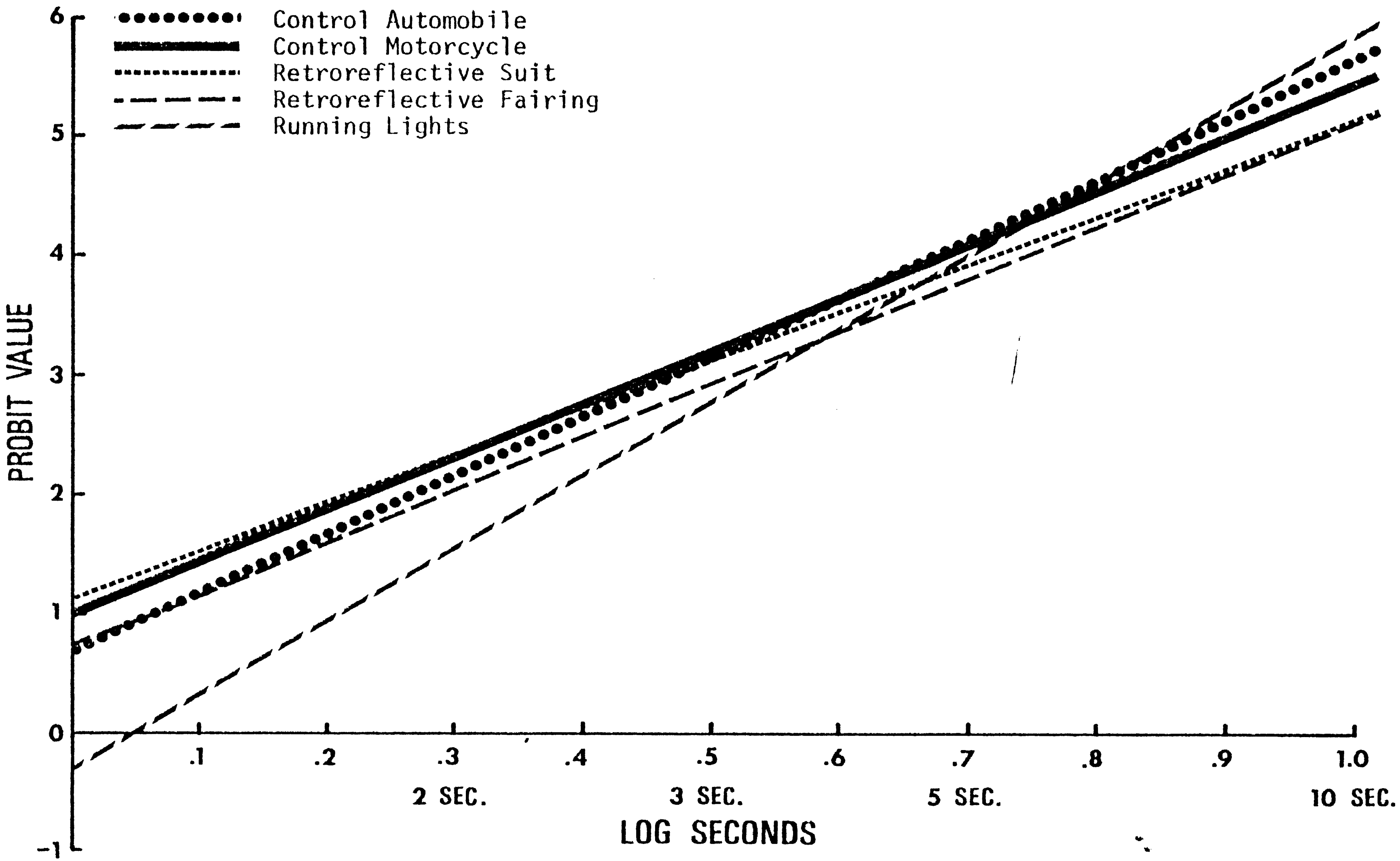

Figure 5-7. Probit results for nighttime conditions--right - cross or left turn maneuver.

TABLE 5-4. Rejected-gap analysis for right - cross or left turn--nighttime condition.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Motorcycle: N = 75, P = .97				Control Motorcycle: N = 165, P = .93				Control Motorcycle: N = 232, P = .91			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Night Car Control	50	.96	.01	.30	71	.97	-.04	-1.21	90	.97	-.06	-1.85*
Retro-reflective Fairing	17	1.0	-.03	-.72	40	.95	-.02	-.46	46	.94	-.03	-.67
Retro-reflective Suit	106	.98	-.01	-.43	152	.94	-.01	-.36	203	.93	-.02	-.76
Running Lights	63	1.0	-.03	-1.39#	133	.96	-.03	-1.11	139	.96	-.05	-1.81*

# indicates .1 level of significance (one-way), * indicates .05 and ** indicates .01.

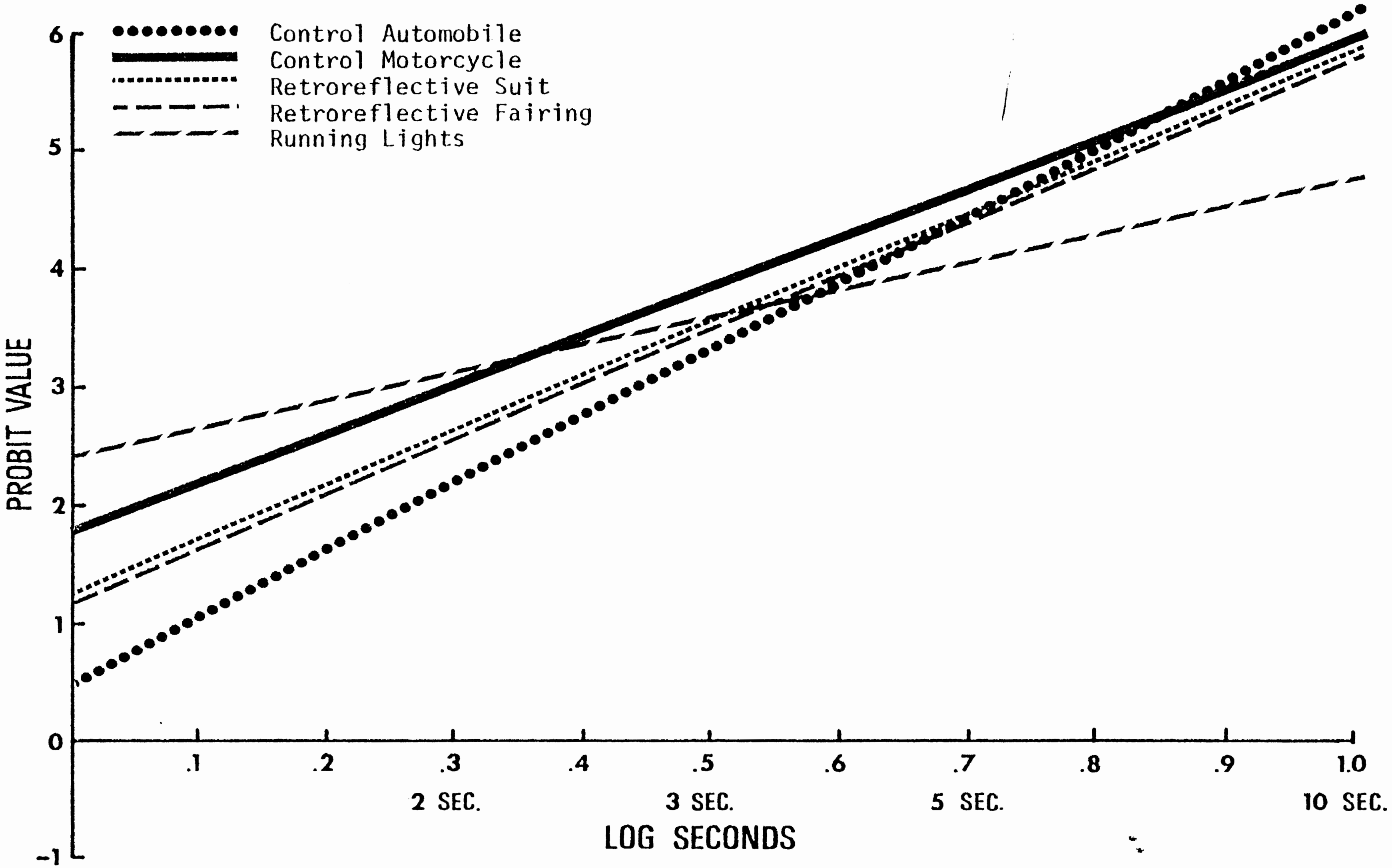

Figure 5-8. Probit results for nighttime conditions--center - left turn maneuver.

Table 5-5 presents the rejected gap analysis for this maneuver. The retroreflective suit, in particular, appears to be associated with significantly reduced probability of short gaps being accepted. As in the case of the daytime treatments with this maneuver, effectiveness continues out to gaps as large as five seconds.

5.2.3 Right-Right Turn. Figure 5-9 presents the probit fits for this maneuver. While all treatments seems better than the control, the differences are small.

Table 5-6 presents the rejected gap analysis for this maneuver. Only the car control condition appears consistently better than the motorcycle control. It is true that the retroreflective fairing treatment appears marginally better, however the *n* is small. In addition, the initial right angle orientation of the vehicles means the headlamps of the subject vehicle could not have impinged on the motorcycle.

The cautious behavior of the subject drivers noted for this maneuver during the day is not evident in the nighttime. Whether this is a real difference or reflects chance variations is not clear.

5.2.4 Summary, Nighttime Treatments. These data suggest that the use of running lights and retroreflective clothing may improve nighttime conspicuity. Running lights appear to be less effective for head-on confrontations than does the retroreflective gear. This is unfortunate, because the retroreflective treatments cannot be of assistance unless the car's headlamps are pointed toward the bike. Therefore, the use of both treatments seems advisable.

5.3 Motorcycle Lateral Position

There is some controversy among motorcyclists as to whether they should ride in the center, right or left portion of the lane. There are a number of points to consider, one of which is the effect on vehicles seeking to maneuver across the motorcycle's path. The present data may provide some insight on this issue.

TABLE 5-5. Rejected-gap analysis for the center - left turn--nighttime conditions.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Motorcycle: N = 143, P = .92				Control Motorcycle: N = 282, P = .86				Control Motorcycle: N = 362, P = .82			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Night Car Control	132	.97	-.05	-1.80*	193	.95	-.09	-3.16**	215	.92	-.10	-3.33**
Retro-reflective Fairing	40	.98	-.06	-1.34#	107	.88	-.02	-.52	112	.88	-.06	-1.49#
Retro-reflective Suit	176	.97	-.05	-1.99*	274	.92	-.06	-2.26*	314	.89	-.07	-2.56**
Running Lights	113	.94	-.02	-.62	268	.91	-.05	-1.83*	284	.91	-.09	-3.27**

# indicates .1 level of significance (one-way), * indicates .05 and ** indicates .01.

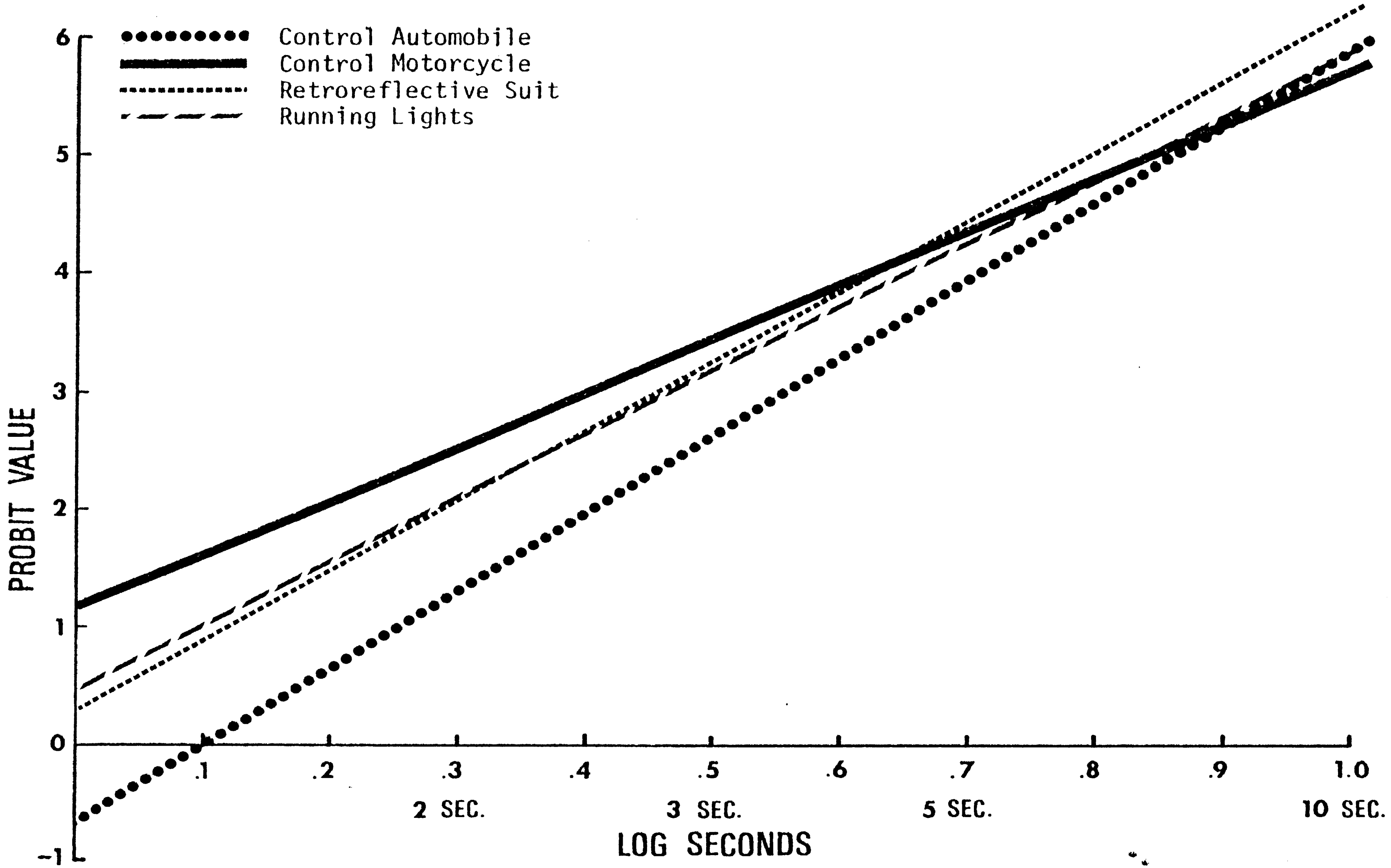

Figure 5-9. Probit results for nighttime conditions--right - right turn maneuver.

TABLE 5-6. Rejected-gap analysis for right - right turn--nighttime conditions.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Motorcycle: N = 128, P = .95				Control Motorcycle: N = 225, P = .91				Control Motorcycle: N = 330, P = .88			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Night Car Control	155	1.0	-.05	-2.82**	216	.99	-.08	-3.85**	253	.96	-.08	-3.43**
Retro-reflective Fairing	41	1.0	-.05	-1.46#	94	.93	-.02	-.60	95	.92	-.04	-1.09
Retro-reflective Suit	106	.96	-.01	-.37	187	.95	-.04	-1.60#	235	.89	-.01	-.37
Running Lights	102	.98	-.03	-1.20	217	.94	-.03	-1.22	255	.93	-.05	-1.93*

# indicates .1 level of significance (one-way), * indicates .05 and ** indicates .01.

It should be noted these data were taken in Florida, where a headlights-on law applies. Therefore, the "control" condition was also with headlights on.

Figure 5-10 through 5-12 present the probit fits for the three maneuvers studied. In all cases the center and left lane positions are associated with the lowest probabiliy of short gaps being accepted, with the right lane position being poorest.

The rejected gap analyses for the lane positions are provided in Table 5-7 through 5-9. Such differences as are present favor the center lane position, with the exception of the center-left turn maneuver, where the left lane position is very close. (It should be noted that in this case, where the concern is with treatments which are poorer than the control, a two-tailed test of significance has been used.)

5.4 Effect of Following Vehicles

It will be recalled that this condition measured the effect on gap acceptance of having an automobile either 50 or 200 feet behind the motorcycle. These data were compared with the control motorcycle and automobile.

Figures 5-13 through 5-15 show the probit results for the three maneuvers. These suggest possible differences favoring the car and both the 50 and 200 foot following distances for the right-cross and left turn maneuver and the 200 foot following distance for the right-right turn maneuver.

The rejected gap analysis (Tables 10 through 12) indicates marginal significance only for the 50 foot condition in the right-cross or left turn maneuver. In the center-left turn maneuver there are significant differences for both the car and the 50 foot condition, but only for larger gaps. Finally, the rejected gap analysis does not support the apparent differences in the probit for the right-right turn maneuver. Differences between treatment and control conditions are generally small and in favor of the control.

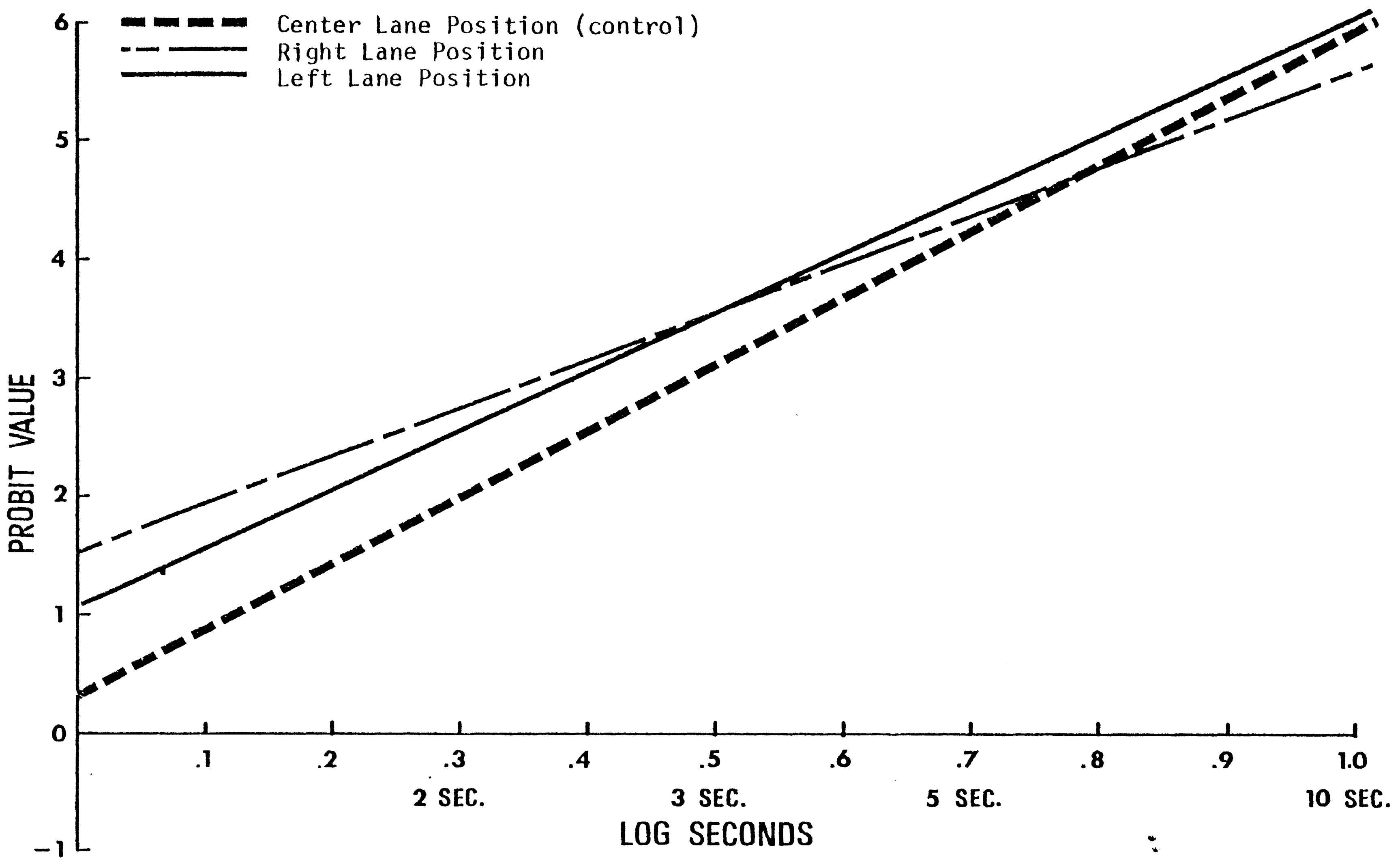

Figure 5-10. Probit results for lateral-lane-position analysis--right - cross or left turn maneuver.

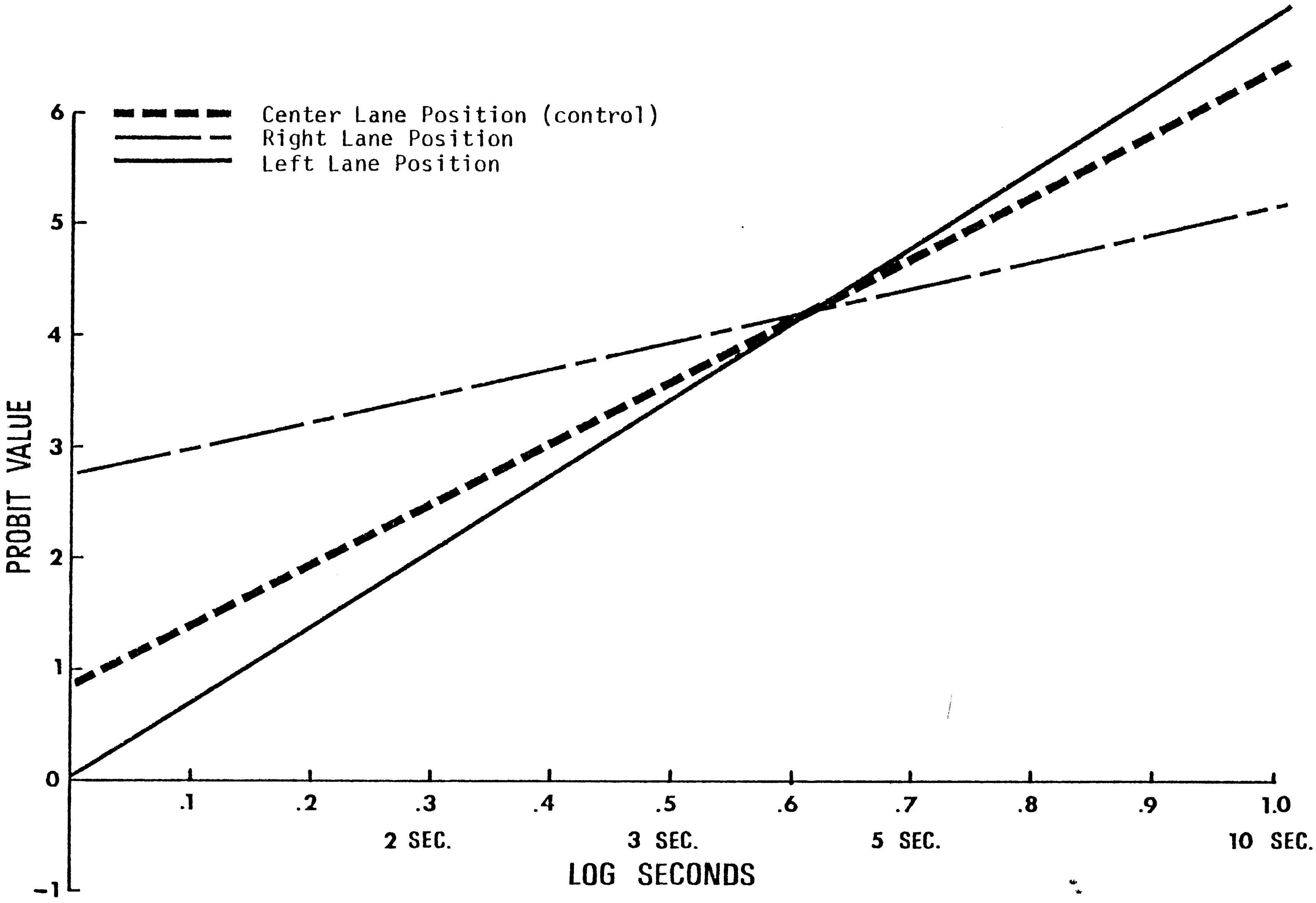

Figure 5-11. Probit results for lateral-lane-position analysis--center - left turn maneuver.

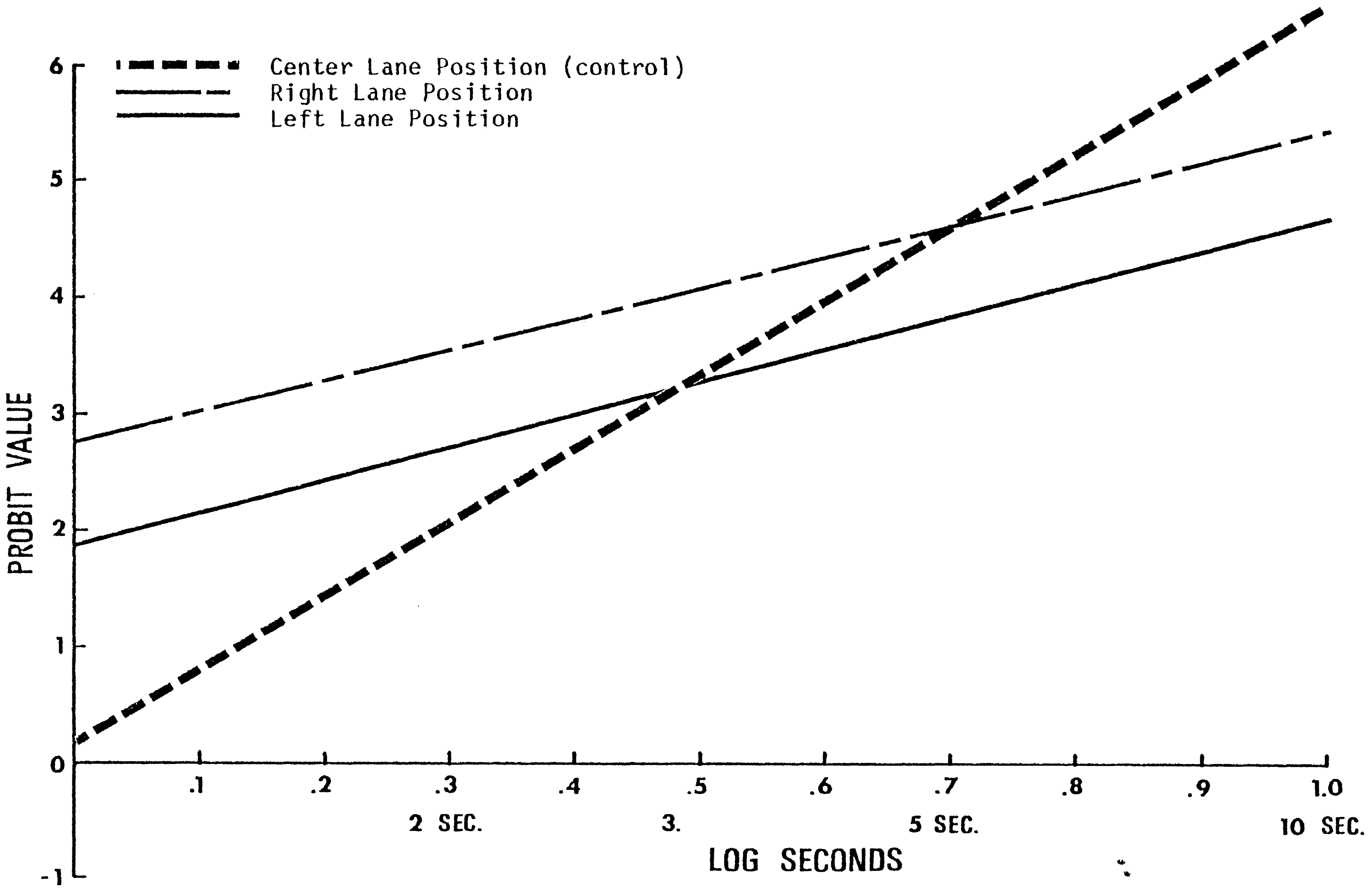

Figure 5-12. Probit results for lateral-lane-position analysis--right - right turn maneuver.

TABLE 5-7. Rejected-gap analysis for right - cross or left turn maneuver--lateral-lane position analysis.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Motorcycle: (lights on, center of lane) N = 234, P = .99				Control Motorcycle: N = 327, P = .97				Control Motorcycle: N = 338, P = .92			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Left Lane Position	66	.94	.05	2.50*	139	.89	.08	3.50**	163	.87	.05	1.78#
Right Lane Position	89	.96	.03	1.80#	136	.88	.09	3.82**	141	.80	.03	1.05

# indicates .1 level of significance (two-way), * indicates .05 and ** indicates .01.

TABLE 5-8. Rejected-gap analysis for center - **left** turn maneuver--lateral-lane position analysis.

Treatment	3 seconds & less				4 seconds & less				5 seconds & less			
	Control Motorcycle: (lights on, center of lane) N = 382, P = .97				Control Motorcycle: N - 482, P = .93				Control Motorcycle: N = 547, P = .87			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Left Lane Position	122	.97	0	0	233	.89	.04	1.82	261	.88	-.01	-.40
Right Lane Position	149	.89	.08	3.72 **	202	.85	.08	3.92 **	207	.85	.02	.72

# indicates .1 level of significance (two-way), * indicates .05 and ** indicates .01.

TABLE 5-9. Rejected-gap analysis for right - right turn maneuver--lateral-lane position analysis.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Motorcycle: (lights on, center of lane) N = 260, P = .99				Control Motorcycle: N = 339, P = .96				Control Motorcycle: N = 402, P = .89			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Left Lane Position	102	.91	.08	3.86**	210	.91	.05	2.41*	240	.89	0	0
Right Lane Position	126	.88	.11	4.84**	194	.86	.10	4.18**	199	.86	.03	1.07

# indicates .1 level of significance (two-way), * indicates .05 and ** indicates .01.

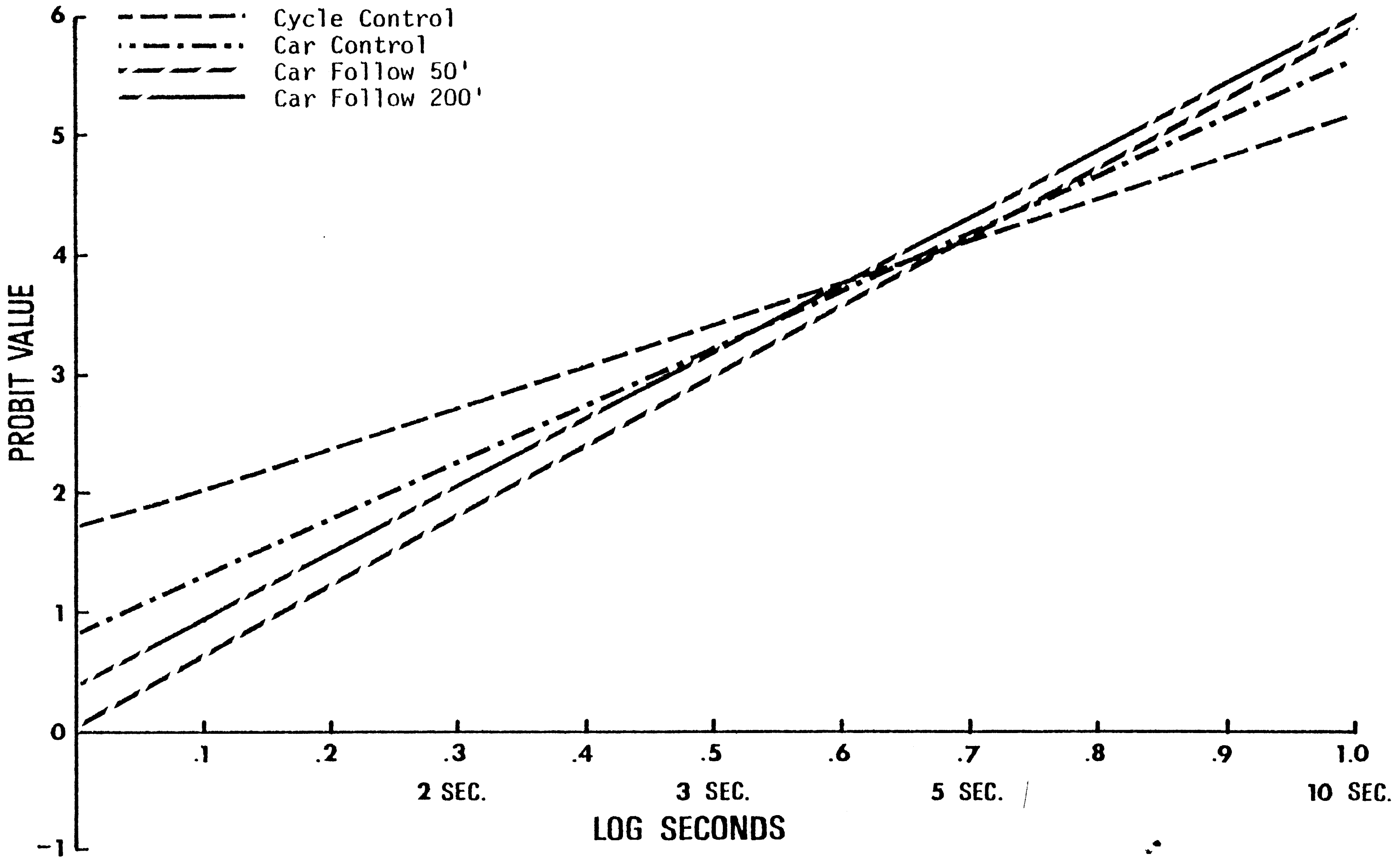

Figure 5-13. Probit results for following-car analysis--right - cross or left turn maneuver.

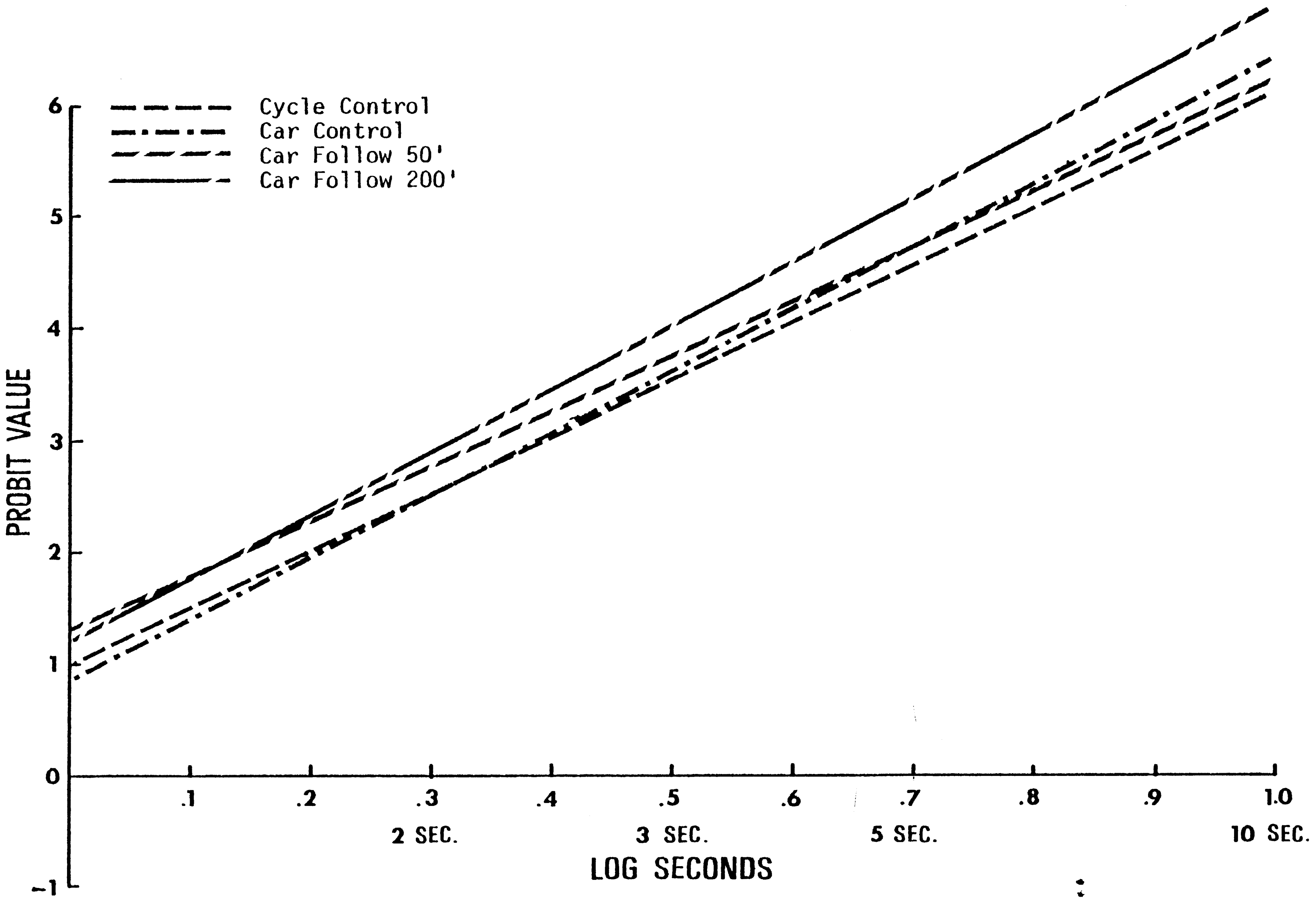

Figure 5-14. Probit results for following-car analysis--center - left turn maneuver.

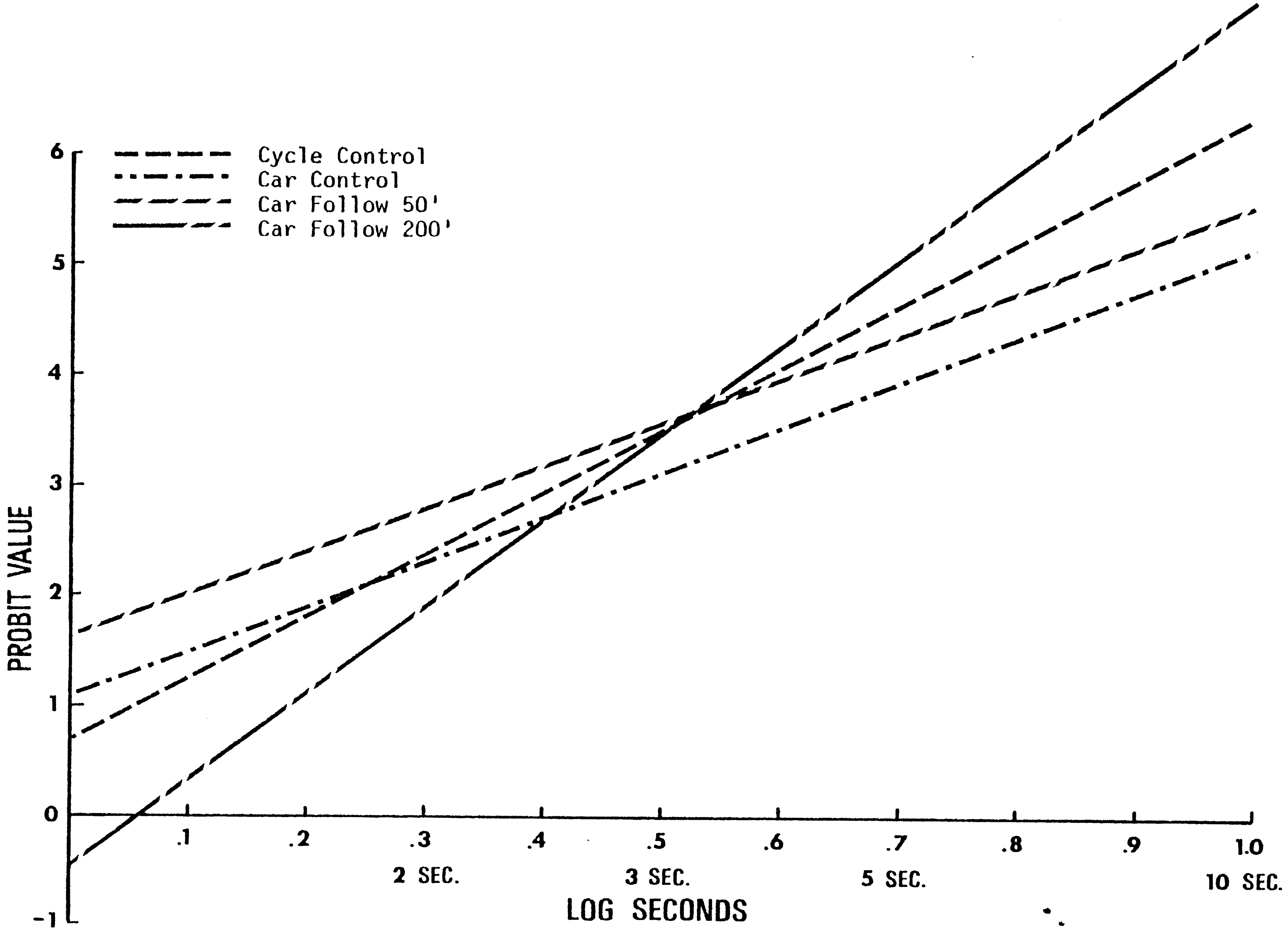

Figure 5-15. Probit results for following-car analysis--right - right turn maneuver.

TABLE 5-10. Rejected-gap analysis for right - cross or left turn maneuver--car-following analysis.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Motorcycle: N = 189, P = .94				Control Motorcycle: N = 281, P = .92				Control Motorcycle: N = 338, P = .90			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
50' Following	112	.98	-.04	-1.62#	166	.96	-.04	-1.66#	215	.91	-.01	-.39
200' Following	72	.94	0	0	165	.92	0	0	235	.88	.02	.76
Car Control	57	.97	-.03	-.89	119	.92	0	0	165	.89	.01	.35

# indicates .1 level of significance (one-way).

TABLE 5-11. Rejected-gap analysis for center - left turn maneuver--car-following analysis.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Motorcycle: N = 168, P = .95				Control Motorcycle: N = 226, P = .86				Control Motorcycle: N = 348, P = .77			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
50' Following	137	.94	.01	.38	231	.90	-.04	-1.36#	273	.83	-.06	-1.84*
200' Following	98	.91	.04	1.28	196	.79	.07	1.98	281	.69	.08	2.26
Car Control	151	.95	0	0	259	.88	-.02	-.68	334	.82	-.05	-1.62#

# indicates .1 level of significance (one-way), * indicates .05.

TABLE 5-12. Rejected-gap analysis for right - right turn maneuver--car-following analysis.

Treatment	3 seconds & less				4 seconds & less				5 seconds & less			
	Control Motorcycle: N = 167, P = .98				Control Motorcycle: N = 248, P = .93				Control Motorcycle: N = 293, P = .88			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
50' Following	88	.97	.01	.50	143	.89	.04	1.37	171	.87	.01	.32
200' Following	69	.99	-.01	-.54	150	.89	.04	1.39	205	.81	.07	2.16
Car Control	152	.97	.01	.57	248	.95	-.02	-.94	325	.93	-.05	-2.13*

* indicates .05

5.5 Moped Conspicuity

In a pilot study using the gap-acceptance methodology, a comparison was made between the conspicuity of an untreated (control) moped and a moped with an orange bicycle flag. Figures 5-16 through 5-18 show the probit plots for the key maneuvers; Tables 5-13 through 5-15 present the rejected gap analyses. The flag appears effective in the center-left turn maneuver, and for larger gaps in the right-cross or left turn maneuver as well.

It is interesting to note that motorists were much less likely to reject short time gaps when confronted by the moped than the motorcycle. Due to speed differences, the moped at three seconds was typically about 75 feet away, the motorcycle 150-200 feet. It would take the subject vehicle just as long in either case to accelerate through and clear the path for the test vehicle. As a matter of fact, given the tighter maneuvering space and lower speeds in the shopping mall, such a maneuver may have taken longer in front of the moped.

Lacking car control data, we do not know whether these response characteristics are typical under such conditions. However, our riders experienced a great deal more difficulty in this brief study than in the motorcycle study. They were nearly run off the road or had to take evasive action on a number of occasions. All in all, these results lead us to believe that the gap acceptance methodology as applied here may not be suitable for use with slower moving vehicles such as mopeds.

5.6 Discussion

5.6.1 Methodology.

Before starting a discussion of the results of this study, it seems appropriate to spend some time considering the methodology which was used to collect the data.

In general, the investigators feel that the gap-acceptance procedure was quite successful in the current application. The data seem meaningful (i.e., intuitively related to the likelihood of

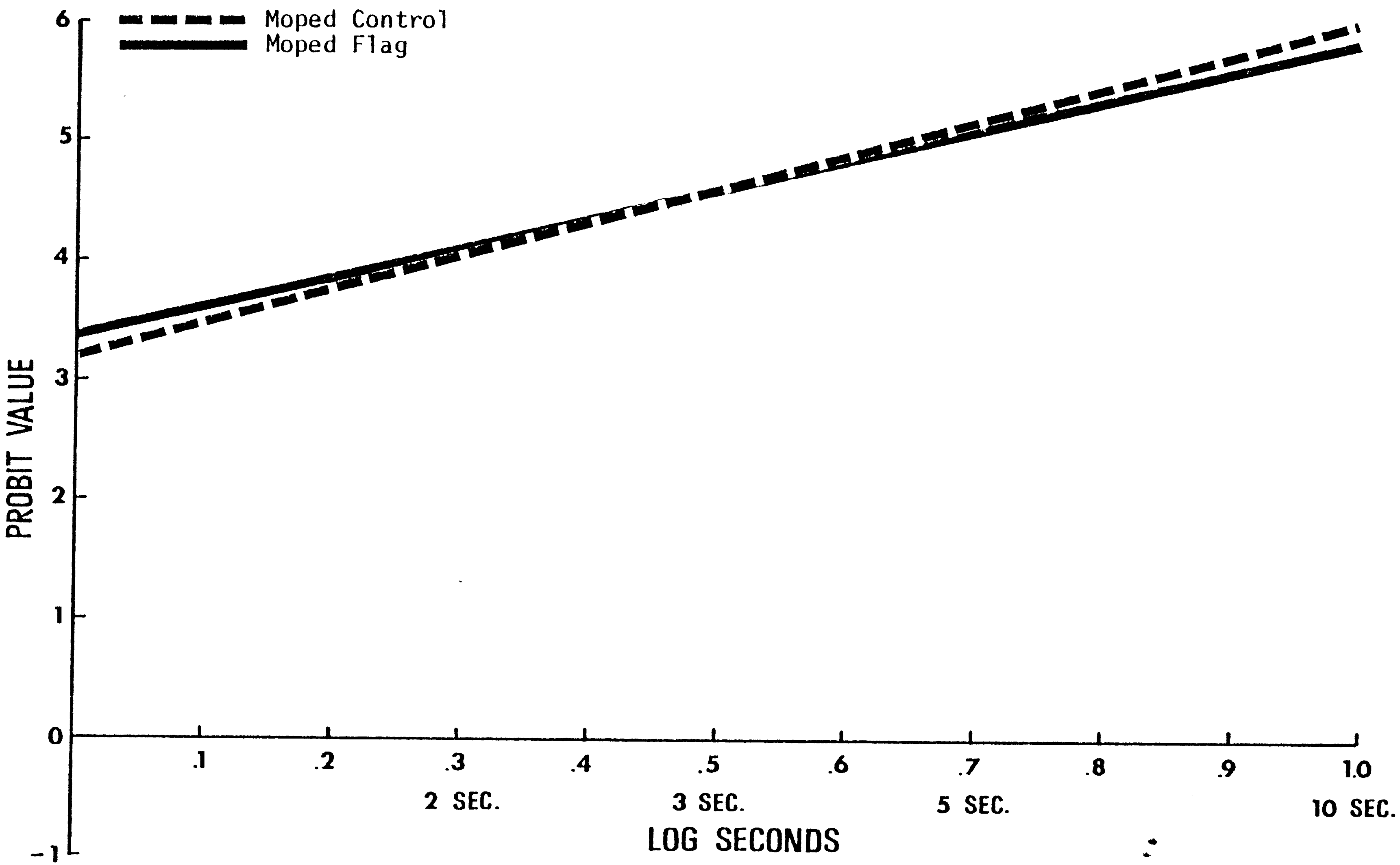

Figure 5-16. Probit results for moped analysis--right - cross or left turn maneuver.

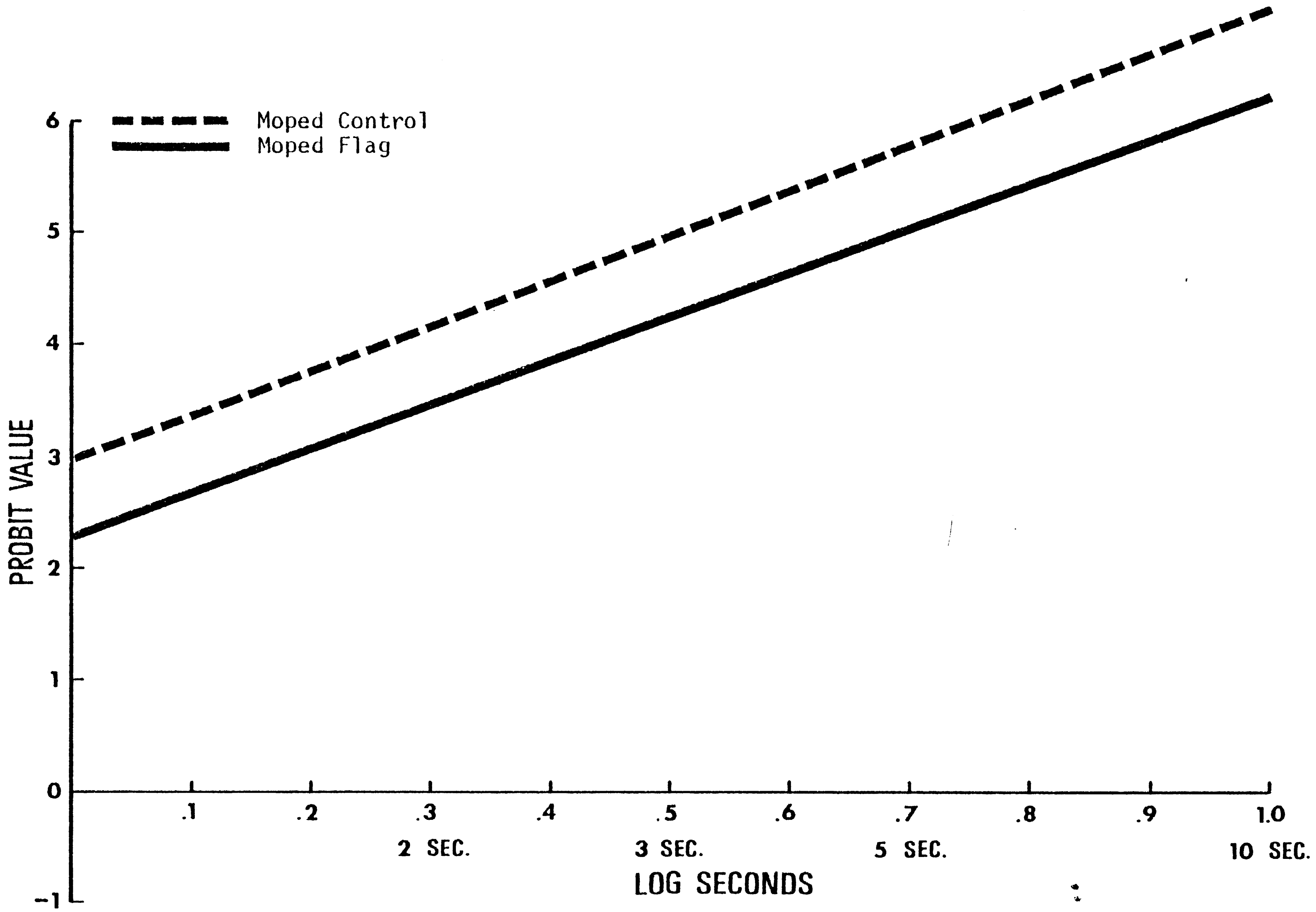

Figure 5-17. Probit results for moped analysis--center - left turn maneuver.

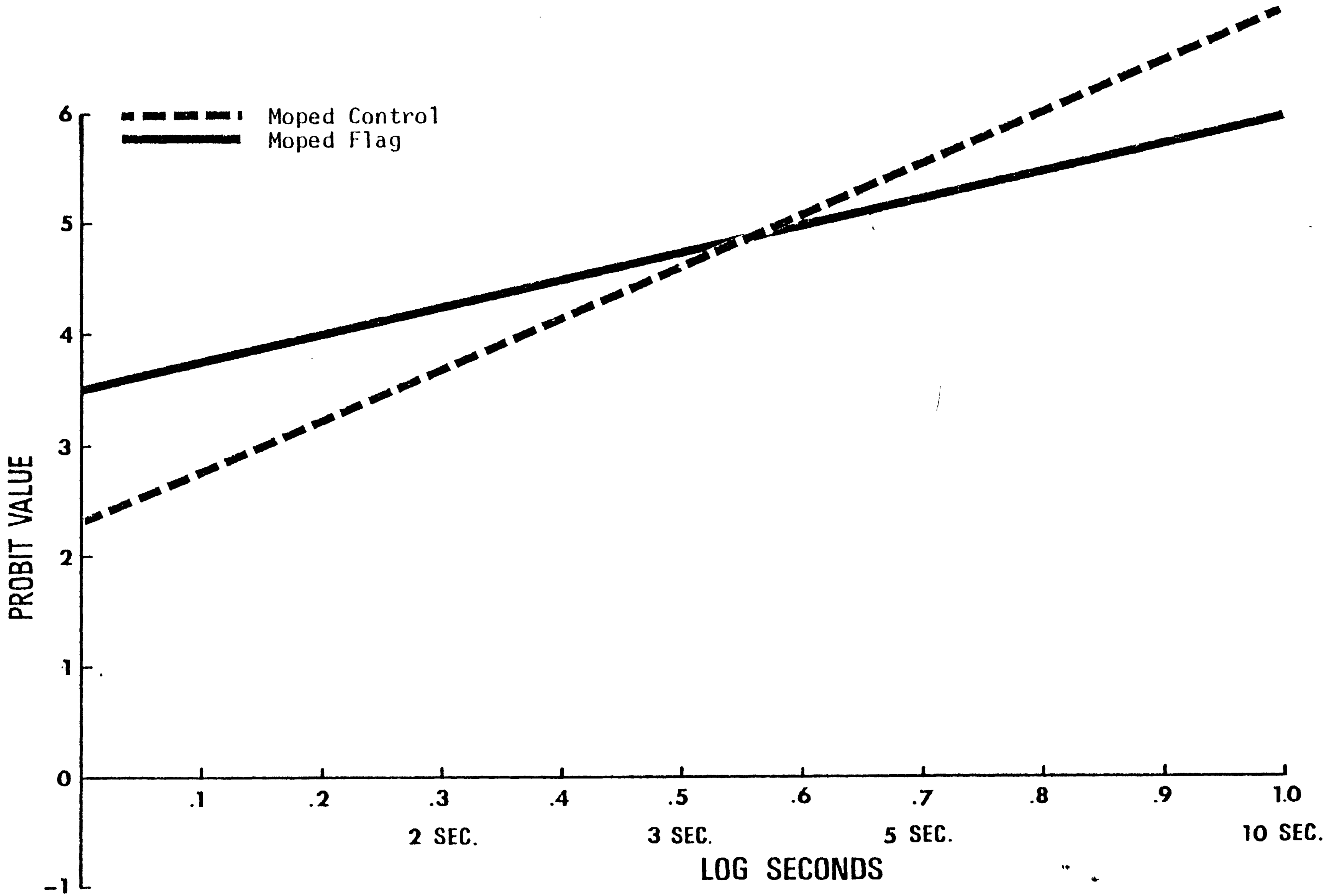

Figure 5-18. Probit results for moped analysis--right - right turn maneuver.

TABLE 5-13. Rejected-gap analysis for right - cross or left turn maneuvers--moped study.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Moped: N = 99, P = .78				Control Moped: N = 152, P =.67				Control Moped: N = 181, P = .63			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Moped with flag	111	.78	0	0	138	.75	-.08	-1.50#	151	.74	-.11	-2.14*

# indicates .1 level of significance (one-way), * indicates .05.

TABLE 5-14. Rejected-gap analysis for center - left turn maneuvers--moped study.

Treatment	3 seconds & less				4 seconds & less				5 seconds & less			
	Control Moped: N = 30, P = .70				Control Moped: N = 45, P = .53				Control Moped: N = 57, P = .47			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Moped with flag	49	.92	-.22	-2.57**	55	.85	-.32	-3.49**	58	.86	-.39	-4.44**

** indicates .01

TABLE 5-15. Rejected-gap analysis for right - right turn maneuvers--moped study.

	3 seconds & less				4 seconds & less				5 seconds & less			
Treatment	Control Moped: N = 74, P - .78				Control Moped: N = 100, P = .66				Control Moped: N = 129, P = .58			
	N	P	P_{diff}	Z	N	P	P_{diff}	Z	N	P	P_{diff}	Z
Moped with flag	59	.76	.02	.27	78	.65	.01	.14	.99	.59	-.01	-.15

accidents), and can be collected quickly, economically, and with relatively simple instrumentation.

Our experience suggests that something like one thousand data points are required per treatment to ensure reliable results. This assumes more or less equal distribution across three maneuvers, or about 300-350 data points per maneuver. It further assumes that the data are concentrated in the short-gap region, i.e., five seconds or less.

Two points should be made regarding the validity of the gap acceptance method in this application. First, the relationship of gap acceptance and accidents is largely unknown at this time. It is true that riding with headlights on seems to be an effective accident countermeasure, as we have noted earlier. The fact that the headlamp on treatment was effective as measured by gap acceptance in this study is encouraging evidence of validity. To some extent the finding of Hurt, also mentioned earlier, that riders wearing high visibility clothing seem underrepresented in the crash data, also indicates the method is valid. However, further validation data would be desirable.

The second point is a limitation already noted in Section 4.2; that is, the method can only measure a fairly general response characteristic on the part of automobile drivers. The fact that differences were found in this study does not mean that other, less general responses cannot account for a significant portion of the problem. If this is the case, it is also possible that different countermeasures may be appropriate.

Finally, a word about safety. The investigators were very concerned about safety; we were, after all, asking our riders to deliberately recreate pre-crash configurations known to be overrepresented in the crash statistics. Our hope was that the high level of attention required to be able to take data would reduce the risk. In the more than twenty thousand miles that were accumulated during the test our riders experienced one minor crash (the rider suffered a scraped knee and the bike was damaged about $200 worth) and several near misses. Interestingly, none of these occurred while data were being taken, but all involved pre-crash configurations of the classic type. Based on this experience, we feel that the method poses no special dangers to the motorcycle riders.

5.6.2 Means for Improving Conspicuity. It appears that there are a number of ways to improve daytime motorcycle-motorcyclist conspicuity that should have a meaningful effect on the behavior of car drivers. The simplest is to drive with the headlamp on at all times. The modulating headlamp is apparently even more effective, but does require some investment on the part of the motorcyclist. High visibility materials seem quite effective as well, but, for some reason, work better when worn by the rider than when fitted to the bike.

The latter finding is somewhat surprising. In the opinion of the investigators, the fluorescent fairing treatment was intuitively a much more effective attention-getter than the fluorescent vest or helmet cover. Yet the field test data indicate the opposite. This suggests that laboratory studies of motorcycle conspicuity can produce misleading results. However, it is not clear why the results came about. One possible explanation is that effectiveness is improved by height. Another is that by emphasizing the rider, speed-spacing judgments are facilitated. This happens because apparent size is an important distance cue. However, it is based on a knowlege of actual size. Most drivers know less about the size of motorcycles, especially motorcycle fairings, than they do about people.

When considered against a criterion of appeal to motorcyclists, the headlamp on and modulating headlamp treatments seem likeliest to be voluntarily adopted. High-visibility treatments on the helmet may have appeal to some riders, especially if they can be convinced the treatments are of value. High-visibility garments, however, may present a problem in acceptance.

For nighttime riding conditions there may be value in wearing retroreflective garments and using running lights. Retroreflective treatments applied to the bike seem less effective but may be of help. It should be pointed out that there are combination fluorescent-retroreflective materials available (the orange and green materials used in this study were of this type), which can provide day and night conspicuity in one package.

Obviously, retroreflective treatments can only be of value when a vehicle's headlamps are directed toward the motorcycle. Thus, there is merit in using another treatment, such as the running lights, to aid when confronted with vehicles in other orientations. It should also be noted that in a real-world setting, a retroreflective jacket would also aid in other types of potential conflict situations, such as overtaking.

While it seems unlikely that retroreflective apparel of the usual type would have much appeal to motorcyclists, they may be willing to accept additional retroreflective trim on their bikes or helmets. It is also possible to treat ordinary fabrics with beads and make them retroreflective without changing their appearance under normal viewing conditions. This may have potential for other vehicles where conspicuity is a problem as well.

The results of the lane-positioning study indicate that, at least insofar as the effect on maneuvering cars is concerned, the motorcyclist is better off in the center of the lane.

There is some evidence from the results of the following car study that the presence of a car close behind a motorcycle may reduce the likelihood of short gaps being accepted, at least for the right-cross and left turn maneuver. While this information is probably of no practical benefit as an accident countermeasure, it does mean that investigators who use gap acceptance in the future must be careful to keep the test vehicle as isolated as possible.

The results of the moped study suggest that the use of a visibility aid such as the fluorescent flag may be beneficial. Indeed, our riders reported they felt much safer with the flag in place and experienced much less trouble with cars. However, for reasons noted earlier, we are doubtful that the gap acceptance methodology as used here for motorcycles is applicable to slower-moving vehicles such as mopeds.

6.0 COST-BENEFIT ANALYSIS

As a final evaluation of each conspicuity treatment's effectiveness, a cost-benefit analysis was carried out. This section describes the analysis and presents its results.

6.1 Assumptions

Three simplifying assumptions were made in the present analysis:

1. It is assumed that in one mile of driving a motorcyclist enters into each of the three types of conflicts (the maneuvers studied in the field test) once. This assumption is likely conservative, and therefore the calculated benefits are likely underestimated.
2. It is assumed that an acceptance of a one-second gap results in a motorcycle-car crash. It is not possible to determine the exact gap that will lead to a crash in each maneuver situation. However, it is likely that a maneuvering vehicle in a one-second-gap situation will be encroaching on the motorcycle's path at the end of one second, making this criterion plausible. Analysis is further simplified by holding this criterion constant across the three maneuvers.
3. It is assumed that all crashes will manifest the same injury-probability data, regardless of which conspicuity treatment (if any) is used. In other words, it is assumed that the conspicuity treatments introduce no biases into the type of injury resulting from a crash.

6.2 Cost-Benefit Analysis Procedure

For each conspicuity treatment the cost-benefit analysis computed the expected accident cost of each conflict between a motorcycle and a car, added the cost of acquiring and using the conspicuity enhancer, and subtracted this sum from the expected accident costs of an untreated (control) motorcycle. In equation form:

$$\text{BENEFITS} = \text{COSTS}_C - (\text{COST}_E + \text{OPERATING COSTS}_E) \qquad (6\text{-}1)$$

where

BENEFITS are the economic benefits to be derived from the use of a particular conspicuity enhancer

COSTS_C are the expected accident costs for an untreated (control) motorcycle

COSTS_E are the expected accident costs for a treated (experimental) motorcycle

OPERATING COSTS_E are the costs of implementing and operating the particular conspicuity enhancer

The following subsections discuss how each term of the equation 6-1 was computed.

6.2.1 Computing the Expected Accident Costs of the Control and Treated Motorcycles. The COSTS_C and COSTS_E terms of the equation were computed in an analogous manner. The first step was to determine, from the probit equation and a table of cumulative normally distributed probabilities, the probability of a driver's accepting a one-second gap. This probability, called here $\text{PROB}_{\text{crash}}$, reflects the likelihood of a collision between a car and a motorcycle given that treatment.

The second step involved estimating the expected costs of each actual crash. The costs of a crash are reflected in the type of injury which occurs. Five injury classifications were used in our analysis:

Fatality
"A" }
"B" } National Safety Council Classifications
"C" }
No Injury--Property
Damage Only (PDO)

Given that a crash has actually occurred, the probability of each type of injury is indicated in Table 6-1 (based on the 1975 Texas motorcycle data).

TABLE 6-1. Probability of particular types of injuries occurring as result of a motorcycle accident (from 1975 Texas motorcycle accident data).

	Overall	Day	Night
Fatal	.017	.012	.031
"A"	.164	.154	.199
"B"	.368	.371	.358
"C"	.114	.110	.127
PDO	.337	.353	.285

Each of the five injury types can be assigned a monetary value corresponding to the losses incurred. This is shown in Table 6-2.

TABLE 6-2. Total average losses for motorcycle accidents.

Fatal[a]	$287,175
"A"[b]	$ 11,900
"B"[b]	$ 3,500
"C"[b]	$ 800
PDO[c]	$ 150

Sources:

[a] U.S. Department of Transportation--NHTSA estimate. <u>1975 Societal Costs of Motor Vehicle Accidents</u> (December, 1976). Page 2, Table 2.

[b] National Safety Council estimates

[c] HSRI estimate

The third and final step in the process involved putting the above information into a working equation: The expected costs of an actual crash were derived by multiplying the monetary cost of an injury type by the probability of that injury type, and by summing across injury types. By multiplying this summation, in turn, by the probability of a crash, we derived the expected accident costs for a particular treatment (or control).

In equation form:

$$\text{COSTS} = \sum_{\text{Injury Type}} \left(\text{PROB}_{\text{Injury Type}} \text{ X } \text{LOSS}_{\text{Injury Type}} \right) \text{PROB}_{\text{Crash}}$$

Table 6-3 shows the expected crash costs for each treatment. It is evident from Table 6-3 that the expected crash costs vary across the maneuvers. In general, however, they are lowest for day treatments 5, 6, 7, and 9, and lowest for night treatments 3 and 4.

6.2.2 Computing the Operating Costs for Each Conspicuity Treatment. The operating costs of an untreated motorcycle were set as the zero baseline. It was assumed that a motorcycle lasted five years and ran 4,500 miles (split into 3,510 daytime and 990 nighttime miles according to Polanis' 1978 data) each of the five years (MVMA Fact Book, 1976).

In general, the per-mile and hence per-conflict cost of using a conspicuity treatment was computed by adding the treatment's purchase price to its energy, maintenance, and replacement costs over five years, and dividing by the total mileage over five years.

Table 6-4 elaborates on the computation for each treatment.

6.3 Cost-Benefit Analysis Results

Table 6-5 shows the per-conflict benefits for each conspicuity treatments. A negative benefit value indicates the treatment is expected to cost more than the benefits derived from the use of the treatment. The daytime data shows that wearing a fluorescent vest yields the highest benefit. This is due in part to its absolute

TABLE 6-3. Expected crash costs (injuries and/or property damage). All figures in dollars per conflict.

	R-RT	C-LT	R-CLT
Day			
1. Cycle Day Control	.0720	.1884	6.0543
2. Orange Fairing	9.0830	.1010	.0418
3. Green Fairing	.000015	1.1435	.0030
4. Orange Suit	.0625	.0000067	.0148
5. Green Suit	.0000077	.000023	.00017
6. Orange Vest	.0014	.000003	.000003
7. Orange Helmet	.0058	.0000134	.0000067
8. Lights On	.0065	.0524	.0045
9. Modulated Headlamp	.0363	.0000335	.0000134
10. Headlamp 1/10th Int.	2.4220	7.399	13.454
Night			
1. Cycle Night Control	.8875	10.0157	.0900
2. Retroreflective Suit	.0178	1.2678	.7607
3. Retroreflective Fairing	.0127	1.205	.1242
4. Running Lights	.0305	38.033	.0006

TABLE 6-4. Operating costs of conspicuity enhancers.

DAYTIME

Conspicuity Treatment	Purchase Cost ($)	Yearly Maintenance Cost ($)	Yearly Energy Cost ($)	Total Operation Cost Per Year* ($)	Total Operation Cost Per Conflict (mile)** ($)
Orange Fairing or Green Fairing	150	10 (to replace fluorescent material)	6 (uses approx. 1 gallon of gas @ $1 for each 15 hours [600 miles]of operation)	46	.0131
Orange Helmet	65 helmet 5 paint 70			14	.0040
Orange Vest	2	2 (buy one new vest each year)		2	.00057
Orange Suit or Green Suit	65 helmet 5 paint 2 vest 72	2 (new vest each year)		16	.00457
Lights-On		7.5 (replace light) 10 (replace battery every 2 years) 17.5	14 (uses approximately 1 gallon of gas @ $1 for each 6 hours [240 miles] of operation)	31.5	.00897
Modulated Headlamp	65	11.38 (according to manufacturer, modulated headlamp uses 65% of both energy and maintenance of lights-on costs)	9.1	33.48	.0095
Headlamp @ 1/10th Intensity		8.75 (maintenance and energy costs computed as 50% of lights-on costs)	7	15.75	.0045

NIGHTTIME

Retroreflective Suit	65 helmet 10 paint 10 vest 85	5 (paint touch-up and vest repair)		22	.0222
Retroreflective Fairing	150	10 (to replace retroreflective material)	6 (uses approximately 1 gallon of gas @ $1 for each 15 hours [600 miles] of operation	46	.0465
Running Lights		5 (replace lights) 6.6 (one battery replacement in 5 years)	7 (computed as 50% of lights-on energy cost)	18.6	.0188

* Based on an average of 3,510 daytime miles for each motorcycle in the U.S.

** Based on an average of 990 nighttime miles for each motorcycle in the U.S.

TABLE 6-5. Benefits per conflict of conspicuity treatments (all figures in dollars).

DAYTIME

Conspicuity Treatment	Expected benefits per conflict by maneuver		
	Right-Right Turn	Center-Left Turn	Right-Cross or Left Turn
Orange Fairing	-9.0241	.0743	5.9994
Green Fairing	.0589	-.9682	6.0382
Orange Suit	.0049	.1838	6.0349
Green Suit	.0674	.1838	6.0496
Orange Vest	.0700	.1878	6.0537
Orange Helmet	.0622	.1844	6.0503
Lights-On	.0565	.1270	6.0408
Modulated Headlamp	.0262	.1789	6.0448
Headlamp 1/10th Intensity	-2.3545	-7.215	-7.404

NIGHTTIME

Conspicuity Treatment Enhancer	Expected benefits per conflict by maneuver		
	Right-Right Turn	Center-Left Turn	Right-Cross or Left Turn
Retroreflective Suit	.8475	8.7257	-.6929
Retroreflective Fairing	.8283	8.7642	-.0807
Running Lights	.8382	-28.064	.0706

percentage of expected crashes (indicating a raised level of conspicuity) plus the fact that these vests are very inexpensive to the motorcyclist. Other treatments that consistently showed strong potential benefits were the green suit, orange helmet, lights-on, and modulating headlamp.

The nighttime data show that the retroreflective suit and fairing are cost-effective on the center-left-turn maneuver. Although all treatments seem equally effective on the right-right-turn maneuver, this is most likely an artifact, since the retroreflective treatments cannot work in this configuration.

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