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FINAL DESIGN AND IMPLEMENTATION PLAN FOR EVALUATING THE EFFECTIVENESS OF FMVSS 108: SIDE MARKER LAMPS AND HIGH INTENSITY HEADLAMPS (ONLY)

Joseph C. Reidy
Gaylord M. Northrop

The Center for the Environment and Man, Inc.
275 Windsor Street
Hartford, Connecticut 06120

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Joseph C. Reidy; Gaylord M. Northrop

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275 Windsor Street
Hartford, Connecticut 06120

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16. Abstract

This report covers the final design and implementation plan for evaluating the effectiveness of FMVSS 108: Side Marker Lamps and High Intensity Headlamps (only). The plan for the evaluation study considers measurability criteria, alternative statistical techniques, laboratory tests, data availability/collectability, resource requirements, work schedule and other factors. The overall objective of the Standard is accident avoidance. In part, this is achieved by requiring side marker lamps which help drivers notice other vehicles and judge distances during darkness or other conditions of reduced visibility. High intensity headlamps have recently been allowed on passenger cars. Their light output is up to double that of existing headlamps, leading to greater nighttime sighting distances and possibly more accidents from increased headlamp glare.

The plan described herein contains nine separate evaluation programs; including one on the cost of complying with Standard. The first program uses mass accident data to analyze the affect of side marker lamps inside collisions. The next three programs are experiments: one a laboratory test of the effects of adverse weather on glare from high intensity headlamps, and the second a field study of sighting distance as affected by high intensity headlamps and side marker lamps, and the third is a lab test of side marker lamp conspicuity. If these initial studies are not sufficient to evaluate the effectiveness of high intensity headlamps and side marker lamps additional programs include: field data collection at hazardous locations for nighttime performance of cars with high intensity headlamps; analysis of mass accident data for overdriving headlamps and glare complaints; field surveys of lighting system usage, headlamp misaiming (or outage). The ninth program presented is the cost sampling plan. In summary it is estimated that the evaluation of side marker lamps and high intensity headlamps could be carried out in about four years at a cost of about $557,000. This figure includes about 8.5 professional staff-years of effort.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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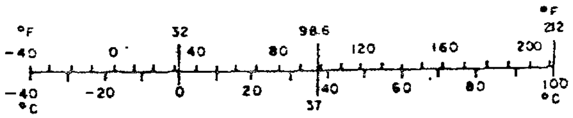
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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CEM

Mr. John Ball
Mr. Diccon Bancroft
Ms. Kayla Costenoble
Mr. Robert Lengel
Mr. Edward Sweeton
Mr. Stephen Thoren

Consultants

Mr. Robert Cromwell
Mr. John Fitch
Dr. Alan Gelfand
Dr. Leonard Hafetz
Dr. Uwe Koehn
Dr. Michael Sutherland

ABBREVIATIONS USED

FMVSS	Federal Motor Vehicle Safety Standard
NCSS	National Crash Severity Study
NASS	National Accident Sampling System
HSRI	Highway Safety Research Institute (Univ. of Michigan)
RFP	Request for Proposal
AIS	Abbreviated Injury Scale
CDC	Collision Deformation Classification
SAE	Society of Automotive Engineers
FHWA	Federal Highway Administration
NHTSA	National Highway Traffic Safety Administration
HLDI	Highway Loss Data Institute
HSRC	Highway Safety Research Center (Univ. of North Carolina)
CPIR	Collision Performance and Injury Report
RSEP	Restraint Systems Evaluation Program
CSS	Continuous Sampling Subsystem
SSS	Special Studies Subsystem
PSU	Primary Sampling Unit
RPM	Revolutions per Minute
GAO	General Accounting Office
BLS	Bureau of Labor Statistics
CEM	The Center for the Environment and Man, Inc.
DOT	Department of Transportation

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Background

This report is the second in a series of three reports which contain final design and implementation plans for evaluating the effectiveness of three selected Federal Motor Vehicle Safety Standards (FMVSS). The three selected FMVSS are:

- FMVSS 105 - Hydraulic Brake Systems in Passenger Cars
- FMVSS 108 - Side Marker Lamps and High Intensity Headlamps (Only)*
- FMVSS 122 - Motorcycle Brake Systems

This report contains the final design and implementation plan for evaluating the effectiveness of FMVSS 108. This Standard originally went into effect on January 1, 1968; however, at that time, the Standard applied only to vehicles 80 or more inches in width—primarily larger commercial vehicles.

Passenger vehicles manufactured in 1969 (January 1, 1969 - December 31, 1969) could meet the requirements for side markers with any combination of lamps or reflectors mounted front and rear. After January 1, 1970, all passenger vehicles had to have an amber lamp positioned as far front and a red lamp as far to the rear as possible on the sides of the vehicle. (Some vehicles achieved this by combining the front and/or rear side marker lamps with front and/or rear lighting components.)

The original FMVSS 108 largely ratified the existing head lighting practices embodied in the Society of Automotive Engineers Standards and Recommended Practices. As of November 1, 1976 NHTSA allowed the manufacturers to provide either a high-intensity rectangular headlamp system or existing lower intensity systems, thus permitting an increase in maximum light output from 75,000 to 150,000 candela.

1.1.1 Purpose of FMVSS 108

The overall purpose of the Standard is to avoid accidents by improving the driver's visual information during darkness or other conditions of reduced visibility. Specifically,

- Side marker lamps are intended to help drivers notice the presence of and judge the distance to other vehicles when the vehicles are at an angle to one another, and
- High intensity headlamps are intended to increase the illumination of the path ahead.

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*The formal title of FMVSS 108 is *Lamps, Reflective Devices, and Associated Equipment*. This Standard covers 15 separate lighting elements.

1.1.2 General Requirements of FMVSS 108

Side Marker Lamps

Currently, all vehicles must be equipped with side marker lamps, an amber lamp positioned as far forward and a red lamp as far to the rear "as practicable." The side marker lamps have to meet the minimum candlepower requirements of SAE Standard J592e. The SAE Standard sets minimum and maximum candela measures which must be taken from a position 15 feet from the side of the vehicle half-way between the front and rear marker lamps.

From *January 1, 1969 to December 31, 1969* the Standard could be satisfied with any combination of lamps or reflectors positioned front and rear as long as the colors were correct--amber forward and red rear. SAE Standard J544e applies to reflex reflectors and sets minimum candlepower reflectance for entrance angle of the light (20 degrees left and right and 10 degrees up and down from the axis of reflector and observation angle, 0.2 and 1.5 degrees from the entrance angle).

Before *January 1, 1969*, no side marking lamps were required.

High Intensity Headlamps

Since *November 1, 1976*, two high intensity rectangular headlamps have been allowed on passenger cars, replacing either two-unit or four-unit conventional headlamps. The high intensity headlamps can have a total maximum highbeam output of 150,000 candela, which is double the output of conventional headlamps. (Lowbeam intensity is about 20 percent higher.) The dimensions and testing requirements of these new beams are given in SAE Recommended Practice J1123. That recommended practice references several other SAE Standards as to specific tests. The critical SAE Standard is J579c because that establishes the photometric design and beam pattern requirements. High intensity headlamps are larger than the regular rectangular headlamps--142 x 200 mm *vs.* 100 x 165 mm or 5.6 x 7.9 in *vs.* 4.5 x 6 in.

Two basic tests are required by the Standard. The first test consists of measuring the intensity of light falling on a test screen 25 feet (7.6 m) from the headlamp unit. The intensity of light is measured at certain points to assure separate vertical and horizontal balance and establish a maximum level of light intensity away from the "hot spot." The second test measures intensities at certain points arranged up to 12 degrees left and right and several degrees up and down. Candela are measured for both upper and lower beam, and must exceed proscribed minima and be within other maxima. The absolute maximum is 75,000 candela for one lamp, or 150,000 for both; however, lower maxima are given for critical angles, such as up and to the left.

1.1.3 Measures of Effectiveness

The overall effectiveness of the Standard is the degree to which it achieves its objective--accident avoidance. Specific measures of effectiveness are:

Side Marker Lamps

- Reduction of side (or angle) collisions at dusk/dawn/nighttime/other low light conditions.
- Increased visibility of cars as measured by an observer's sighting distance.

High Intensity Headlamps

- Reduction in accidents (or emergency maneuvers) resulting from overdriving headlamps.*
- Increased driver sighting distance with high intensity headlamps.
- Decreased driver sighting distance due to glare from high intensity headlamps.
- Increased frequency of glare/blinding complaints in accidents.

1.1.4 Means of Complying with the Standard

Side Marker Lamps

- Before *January 1, 1969* regular passenger vehicles were not required to have any side markers. However, due to modeling considerations some earlier models had various lights which were visible from the side.
- Between *January 1,1969 and December 31, 1969* vehicles could satisfy the Standard for side marker lamps in one of four ways:
  (1) Using one red and one amber reflex reflector.
  (2) Using one red and one amber side marker lamp.
  (3) Using a red side marker lamp and an amber reflex reflector.
  (4) Using a red reflex reflector and an amber side marker lamp.

The amber element should be as far front and the red element as far to the rear as practicable on each side of the vehicle.

- After *January 1, 1970* cars had to have lamps for both forward and rear side markers. Some models achieved this by enlarging the front and/or rear lighting group so that it could be seen from the side; other models had totally separate side marker lamps.

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*"Driver ability to see" is a variable depending on many factors such as fog/rain/snow, windshield cleanliness, headlamp aiming, and headlamp cleanliness, as well as the driver's own visual abilities.

High Intensity Headlamps

There is no requirement for the use of high intensity lighting systems. A restriction on candlepower output was removed for passenger vehicles manufactured after November 1, 1976, allowing high intensity rectangular two-headlamp systems.* These headlamps can produce twice the high beam output of regular lights and about 20 percent more low beam output.

The Type 2B high intensity headlamps are of a larger size than regular rectangular headlamps. This change was desired by the manufacturers and is not a requirement of the Standard. The increased illumination could have simply been increased by a heavier filament or through the use of a quartz-halogen light source in existing headlmap designs.

1.1.5 Primary and Secondary Effects of Compliance

Both side marker lamps and high intensity headlamps will only have an effect when they are used during darkness or other conditions of reduce visibility.

The primary effects of side marker lamps will be in situations where vehicles are approaching one another at an angle. The side marker lamps should aid vehicle identification and distance judgment thus leading to accident avoidance. There are no significant secondary effects of side marker lamps. One speculative effect is that drivers will depend on the side marker lamps for visual use while driving and thus reactions to and identification of Pre-Standard cars under poor visual conditions would be even further degraded.

The primary effect of the high intensity headlamps will be that the roadway will be better illuminated. However, this increased illumination may lead to increased glare for other drivers. The degree to which the increased illumination helps avoid accidents depends largely on driver characteristics, e.g., how far ahead the driver looks. Two potential secondary effects of the high intensity headlamps are (1) that the headlamps may make other drivers aware of the location of the Post-Standard Vehicle, and (2) that the brighter lamps may cause greater numbers of animals to be "frozen" in the roadway leading to an increase in such potentially hazardous situations.

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*The *New York Times* reported a proposed revision of FMVSS 108 which would allow high intensity headlamps of all configurations, not only the type 2B. This revision is expected to become effective during the summer of 1979. [6]

1.1.6 Real World Performance of the Standard

The estimated effect of side marker lamps in reducing side collisions at night has been of the order of 1 percent [1]. The effect of the lamps may be larger during periods of dusk/dawn/adverse weather where running lights (but not headlamps) are in use.

High intensity headlamps are currently being provided on some new 1978 models. Therefore, no accident data has yet been analyzed to provide any estimate of the effects of these headlamps in reducing (or possibly increasing) certain types of nighttime accidents. Night accidents caused 56 percent of motor vehicle deaths and about 36 percent of all accidents in 1975 [2].* Overdriving headlamps seen to be a prevalent behavior in nighttime driving. Observation of headlamp usage shows that the high beam usage--where the new high intensity lamps would provide the greatest improvement--is generally low, about 5 percent of nighttime driving [3].

The high intensity headlamps will increase candlepower output about 20 percent on low beam and up to 100 percent on high beams. However, this increased output does not increase visibility distance proportionately. Because illumination levels follow an inverse square law, sighting distance could be increased potentially between 20 and at most 40 percent on high beam and much less on low beam. However, the increased illumination for one driver can result in increased glare for other drivers. Headlamp glare has been cited as a factor in up to 4 percent of night accidents [4].

The final factors in the real world performance of the headlamps relate to the driver's behavior--how far down the road he looks, how he uses high lights, how he looks when there is opposing glare, whether he is sober, etc. Therefore the effect of the headlamps can not be realistically evaluated in laboratory experiments.

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*California Highway Patrol data indicate alcohol involvement in about three-quarters of all fatal or injury accidents. Two-thirds of these drivers were legally drunk [2]. Results of Alcohol Safety Action Project Studies indicate that the number of drunken drivers is significantly greater at night [5].

1.2 Summary of Evaluation, Cost Sampling, and Work Plan

The plan to evaluate the effectiveness and cost of FMVSS 108 comprises nine analyses. They are:

- Analysis of Mass Accident Data: Side Collisions
- Laboratory Tests of Adverse Weather Effects on Glare (Headlamps)
- Sighting Distance Field Test (Side Marker Lamps and Headlamps)
- Laboratory Test of Conspicuity of Side Marker Lamps
- Field Data Collection at Hazardous Locations (Headlamps)
- Analysis of Mass Accident Data: Overdriving and Glare
- Survey of Lighting System Usage (Side Marker Lamps and Headlamps)
- Misaiming of Headlamps and Light Outage Rates
- Cost Data Analysis.

1.2.1 Analysis of Mass Accident Data: Side Collisions

This analysis is concerned with evaluating the performance and effectiveness of the Standard with regard to side marker lamps, using mass accident data. The analysis is directed toward estimating the reduction in the rate of side collisions occurring at dusk and nighttime in vehicles equipped with side marker lamps. The effect of side marker lamps may be greatest when running lights are one, but the headlamps are not. Portions of the following data will be used: HSRI data files, Texas, North Carolina, New York, Virginia and Florida.

1.2.2 Laboratory Tests of Adverse Weather Effects on Glare (Headlamps)

This analysis is concerned with examining the performance of high intensity headlamps under adverse environmental conditions. Under conditions of reduced visibility due to rain, snow or fog, the amount of light that is scattered is critical, as well as the light transmitted down the road. Environmental test facilities which can simulate adverse conditions will be located. Various types of headlamps will be obtained and a test rig devised. Using appropriate instruments, comparative tests of headlamps will be conducted under adverse conditions in which beam penetration and backscattering will be measured. This is not envisioned to be a costly or large-scale study.

1.2.3 Sighting Distance Field Study (Side Marker Lamps and Headlamps)

This part of the evaluation is designed to collect data on drivers' nighttime sighting distance as it is affected by headlamp systems, glare and targets. Previous research by medical and traffic safety personnel will be synthesized. A field experiment, which will be designed and tested, shall consider misaiming of headlamps, subject visual capabilities, headlamp and seat height, glare, and varying targets (no lights, parking light or headlamps). The number of effects which can be included in an expanded field test shall be determined from pilot testing to get preliminary estimates of effects and interactions.

1.2.4 Laboratory Tests of Conspicuity of Side Marker Lamps

This portion of the evaluation is directed toward determining whether certain side marker lamp designs are more noticeable than other designs. The effort will determine how noticeable a side marker lamp on a vehicle is by measuring how intense a slide projected image of the vehicle with a particular lamp must be for a subject to identify the image. The measures of recognition would be the intensity of the vehicle image, the time to recognition at different intensity levels, and the source of identification--side marker lamps or other light sources.

1.2.5 Field Data Collection at Hazardous Locations (Headlamps)

This analysis is directed toward evaluating the differences in performance between cars with high intensity headlamps *vs.* cars with regular headlamps in hazardous locations at night. A new data collection will be conducted to collect both exposure and disability data (accidents and traffic conflicts). The traffic conflict methodology developed in the 1960's and applied to a variety of problems will be adapted to this study. The initial steps will be to identify and select hazardous locations and train selected data collection teams. Traffic conflict data must be automated prior to data analysis.

1.2.6 Analysis of Mass Accident Data: Overdriving and Glare (Headlamps)

This analysis is concerned with evaluating the performance and effectiveness of the Standard with regard to high intensity headlamps, using mass accident data. The study is conducted in two parts. The first part of the mass accident analysis is concerned with estimating the frequency with which drivers are involved in accidents due to overdriving their headlamps. Any reduction in such accidents, due to high intensity headlamp usage will be investigated. The second part of the mass accident analysis is concerned with estimating the frequency of accidents attributed to glare blinding. In each part, portions of the following data will be used: HSRI data files, Texas, North Carolina, New York, Virginia and Florida.

1.2.7 Survey of Lighting System Usage (Side Marker Lamps and Headlamps)

This part of the evaluation is designed to determine the patterns of lighting system usage for both headlamps and parking lights. Factors to be considered include geographical area, highway type, traffic density and following and opposing vehicle behavior. Time of day will be recorded and ambient light conditions monitored. The literature describing previous studies will be reviewed and a data collection methodology established regarding data form, light meters and personnel protocol. Personnel will be trained in selected test areas. The survey data will be computer processed and analyzed. Detailed data on standard errors of usage estimates will be provided.

1.2.8 Misaiming of Headlamps and Light Outage Rate

This portion of the evaluation is directed toward (1) determining the prevalence and degree of misaiming of headlamps in the vehicle population; and (2) conducting a survey to estimate how often vehicle lighting systems are totally or partially failed. In the first part of the study, the literature will be reviewed to determine factors relevant to headlamp misaiming and the size of effects. Based on the review, a test methodology will be developed that will include test and equipment required, personnel training, site selection and data recording. The results of the misaiming test will be utilized in the second part of the study.

In the second part of the study, literature and data on defect and outage rates of headlamp systems will be collected. If required, the need for additional data will be specified and the data collection will be executed and analyzed.

1.2.9 Cost Sampling Plan

The cost sampling plan is concerned with the determination of direct costs to implement FMVSS 108. Cost categories are confined to direct manufacturing, indirect manufacturing, capital investment (including testing), manufacturer's markup, dealer's markup and taxes. A frequency sampling plan to determine the costs of side marker lamps has been developed which assumes that the manufacturer's cost of compliance varies according to manufacturer or market class. Since not all models will have, and perhaps not all manufacturers will offer models with high intensity headlamps, a different sampling plan to determine the incremental cost of the high intensity headlamps may be necessary. Initially, it is suggested that costs be collected on one model with the high intensity headlamps from each major American manufacturer. If these costs differ much from one another, then more detailed investigation may be worthwhile.

1.2.10 Work Plan

The work plan for the evaluation study of FMVSS 108 is divided into a total of nine Tasks. Assuming all Tasks are carried out, the estimated resources required for evaluating the effectiveness of and cost of the Standard, amount to $557,000. This figure includes estimated requirements of 8.5 staff-years to carry out the studies.

Task 1 is concerned with an analysis of side collisions with mass accident data. It is estimated that six months will be required for the completion of the Task 1 study during the first year. The total resources required for Task 1 are estimated to be $29,000. This total includes accomplishing the Task effort with 0.5 staff-years and $5,000 for data processing.

Task 2 is concerned with examining the performance of high intensity headlamps under adverse environmental conditions simulared in laboratory tests. It is estiamted that six months will be required for the completion of the Task 2 work, which would occur during the first year of the evaluation study. The total resources required for Task 2 are estimated to be $46,000. This total includes accomplishing the Task effort with 0.8 staff-years and $6,000 for laboratory costs and equipment costs.

Task 3 is designed to collect data on drivers' nighttime sighting distance as it is affected by headlamp systems, glare and targets. It is estimated that six months will be required for the completion of the Task 3 study. The Task effort can be begun during the first year. The total resources required for Task 3 are estimated to be $112,000. This total includes about two staff-years of effort, $5,000 each for equipment and laboratory costs, and $2,000 for data processing.

Task 4 is directed toward determining whether certain side marker lamp designs are more noticeable than other designs. It is estimated that only six months will be required for the completion of the Task 4 study. The Task will not begin until 16 months after initiation of the Standard evaluation. This will allow taking into consideration the results of the analysis of side collisions (Task 1), sighting distance (Task 3) and adverse weather conditions (Task 2). The total resources required for Task 4 are estimated to be $46,000. This total includes accomplishing the Task effort with 0.8 staff-years and $6,000 for equipment and laboratory costs.

Task 5 deals with evaluating the effects of high intensity headlamps on the performance of cars at hazardous locations at night. It is estimated that twelve months will be required for the completion of the Task 5 field study. In addition to a rather lengthy data collection phase, the Task is delayed until 22 months after initiation of work to permit a greater sampling of vehicles with high intensity headlamps. The total resources required for Task 5 are estimated to be $70,000. This total includes about 0.8 staff-years of effort, $30,000 for field data costs and $2,000 for data processing.

Task 6 is concerndd with the analysis of overdriving and galre effects using mass accident data. It is estimated that six months will be required for the completion of the initial analysis in Task 6. Since both parts of the analysis require mass accident data that include a sufficient population of vehicles with high intensity headlamps, a reanalysis is scheduled at the end of the fourth year of the study. The total resources required for Task 6 are estimated to be $51,000. This total includes accomplishing the Task effort with 0.9 staff-years and $6,000 for data processing.

Task 7 is a survey study to determine the patterns of lighting system usage for both headlamps and parking lights. It is estimated that one year will be required for the completion of the Task 7 study, which can commence early in the fourth year of the study. The total resources required for Task 7 are estimated to be $76,000. This total includes about 1.2 staff-years of effort, $20,000 for field data costs, $4,000 for equipment costs and $2,000 for data processing.

Task 8 is designed to determine the prevalence and degree of misaiming of headlamps and outage rates of headlamp systems. It is estimated that nine months will be required for the completion of the Task 8 study, even assuming that additional data on defect and outage rates of headlamp systems must be collected in the second part of the Task effort. The costing of this Task assumes the collection and analysis of additional data. The Task 8 study will not begin until the beginning of the fourth year of the overall evaluation study. This will permit a sufficient sample of vehicles with high intensity headlamps. The total resources required for Task 8 are estimated to be $86,000. This total includes 0.7 staff-years of effort, $31,000 for equipment, $25,000 for field data costs and $1,000 for computer processing.

In summary, the suggested approaches for evaluating the effectiveness and cost of this Standard require about four years and $557,000, if all Tasks are undertaken. Savings of about $100,000 are possible if the effects of side marker lamps are successfully evaluated early in the study.

1.3 References for Section 1

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5. Smith, Thomas J. *Trends in Drinking Driving at Night.* Virginia Highway and Transportation Research Council, Charlottesville, Virginia, May 1975 (VHTRC 75-R52).

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2.0 APPROACHES TO THE EVALUATION OF FMVSS 108

The purpose of the Standard is to help the driver to avoid accidents by improving the available visual information during darkness or other conditions of reduced visibility. This study is restricted to the effects of only two items covered by the Standard--side marker lamps and high intensity headlamps.

2.1 Problems in Evaluating the Standard

Some problems with evaluating this Standard are:

1. The effects of side marker lamps has been previously estimated as small [1].
2. The effect of high intensity headlamps is unknown because widespread use is new. Secondly, the fact that low beams are used in the majority of nighttime driving reduces the potential effectiveness of the new headlamps.
3. Glare is a potential underdesirable by-product of high intensity headlamps. In estimates of the frequency of accidents due to glare involvement, the reliability of reported glare blinding is questionable.
4. High intensity headlamps should have a positive effect on nighttime accidents at hazardous locations. However, it may be difficult to identify hazardous locations where nighttime visibility is a problem. Also, given the low rate of accidents at any one location, surrogate measures of unsafe performance are used--emergency maneuvers.
5. Information to be derived from controlled laboratory type experiments do not directly measure the effectiveness of the Standard in real world situations.

2.2 Proposed Evaluation Approaches

Tables 2-1 and 2-2 address the results of each of the evaluation approaches. Some approaches will provide information on both the side marker lamps and high intensity headlamps; other approaches deal with only one narrow aspect of the Standard. As had been shown in the previous section, many of the approaches are combined into Tasks because of common elements. The twelve approaches are:

• (Analysis of) Side Collisions • Conspicuity of Side Marker Lamps • Selective Repeal of Side Marker Lamp Requirements	Side Marker Lamps
• Lighting System Usage • Lighting System Outage • Sighting Distance Experiment	Side Marker Lamps and High Intensity Headlamps

• Overdriving of Headlamps • Glare Complaints • Hazardous Locations • Adverse Weather Conditions • Misaiming of Headlamps • Selective Introduction of High Intensity Headlamps	High Intensity Headlamps

TABLE 2-1

SIX APPROACHES FOR EVALUATING THE EFFECTIVENESS OF SIDE MARKER LAMPS

Approach	Description Section	Results
• Analysis of Side Collisions	3.1	Estimate of the reduction of side collisions due to side marker lamps.
• Sighting Distance Experiment	3.7	As a secondary by-product of light conditions under which side marker lamps are most conspicuous will be determined.
• Lighting System Usage	3.5	Estimate of the times (and light conditions) when lights are actually used. This result will be used to determine if the potential effect of side marker lamps could be greater than estimated, i.e., the result of the Analysis of Side Collisions understates the potential effect of the lamps.
• Lighting System Outage	3.6	Estimate of the outage rate of side marker lamps. Outage of such lamps would have the same effect as not using them properly, and thus reducing their potential effect.
• Conspicuity of Side Marker Lamps	3.10	Estimates of the visibility of different side marker lamp designs.
• Selective Repeal of Side Marker Lamp Requirements	3.11	If the Analysis of Side Collisions shows no significant results, the side marker lamp requirements might be reduced. The purpose of this approach is to monitor the rate of side collisions to determine if there is any adverse effect of a selective repeal of the side marker lamp requirements.

TABLE 2-2

NINE APPROACHES FOR EVALUATING THE EFFECTIVENESS OF HIGH INTENSITY HEADLAMPS*

Approach	Description Section	Results
• Hazardous Locations (Speculative)	3.4	Estimate of changes in the rate of evasive or emergency manuevers and accidents at "hazardous" locations at night due to high intensity headlamps.
• Sighting Distance Experiment	3.7	Estimates of the relative effects of high intensity headlamps (1) improving sighting distance due to increased illumination; and (2) decreasing sighting distance due to increased glare from opposing or following cars.
• Overdriving Headlamps (Speculative)	3.2	Estimate the reduction in single vehicle nighttime accidents due to overdriving headlamps. Results from this study should be related to the Hazardous Location study.
• Glare Complaints (Speculative)	3.3	Estimate the increase in accidents caused by increased glare blinding due to high intensity headlamps. Results of this study should correspond to the results of the Sighting Distance Experiment and Misaiming of Headlamp studies.
• Lighting System Usage	3.5	Estimates the light, highway and traffic conditions which affect the usage of headlamps. The results of this survey would be combined with the Sighting Distance Experiment results to determine if the effect of the high intensity headlamps could be improved by proper usage.
• Lighting System Outage	3.1	Outage rate decreases effectiveness and has some effects similar to misusage of headlamps.
• Misaiming of Headlamps	3.9	Estimates the misaiming rates for vehicles-in-use with high intensity headlamps and regular headlamps. Misaiming is to be measured in terms of direction of individual beams and between headlamp beams as well as other characteristics of the beam--intensity, light gradients, effect of vehicle loading, etc. Results will give an estimate of frequency of undesirable conditions such as misaiming, which causes glare.
• Adverse Weather Conditions	3.8	Measures the performance of high intensity headlamps relative to regular headlamps in terms of penetration and backscatter under conditions of rain/snow/fog.
• Controlled Experiment: Selective Introduction of High Intensity Headlamps	3.12	If no significant effect of high intensity headlamps is found in any other study, the only remaining method of evaluation is to equip models of the same make/model/model year with two different intensity lights and then monitor the nighttime accident frequency of these vehicles.

*Since high intensity headlamps have been allowed only recently, data are currently being collected.

2.3 Organization of the Effectiveness Evaluation Plan

The general approach to evaluating the effectiveness of any Standard is to undertake first those evaluation tasks which:

- Can be done early.
- Show significant promise of achieving success in evaluating the effectiveness of the Standard.
- Can be performed relatively inexpensively.

If appropriate data are available in the mass accident data files available from states, and detailed accident data bases such as RSEP, MDAI, NCSS and (in the future) NASS, then statistical analyses are usually the first recommended task(s). In some instances, clinical analyses of available data, surveys, and/or preliminary field or laboratory tests may be appropriate to augment and/or enhance the results expected from the first round of statistical data analyses.

The initial statistical and supporting analyses and tests usually occupy approximately the first year of the evaluation program (time for preparation of Requests for Proposals, proposal review, and contracting is included). The first major decision point is then reached. For some Standards, the initial analyses may be adequate to evaluate the Standard with satisfactory statistical confidence levels. In the case of other Standards, the initial analyses will provide only the basis for conducting surveys, field and laboratory tests, and additional detailed data collection and analysis efforts. As much as two, three or more years of work may be required, and there may be several additional decision points, where NHTSA can decide whether the evaluation process is adequate or should be continued.

CEM has outlined evaluation programs lasting from three to six years. In each case, it is CEM's judgment that there is a reasonably high probability that, by the end of the program, the effectiveness of the Standard will have been satisfactorily evaluated. However, in the event the issue remains in doubt, a number of "Next Possible Steps" are outlined.

Figures 2-1 and 2-2 indicate flow diagram/decision trees for evaluating the effectiveness of FMVSS 108. Two separate flow chart/decision trees are presented for this evaluation. The first deals with Side Marker Lamps, the second with High Intensity Headlamps. Several Tasks apply to both of these aspects of FMVSS 108. The integrated evaluation program Work Plan is presented in Section 5.
A brief description of the Tasks and Decision Points is given below.

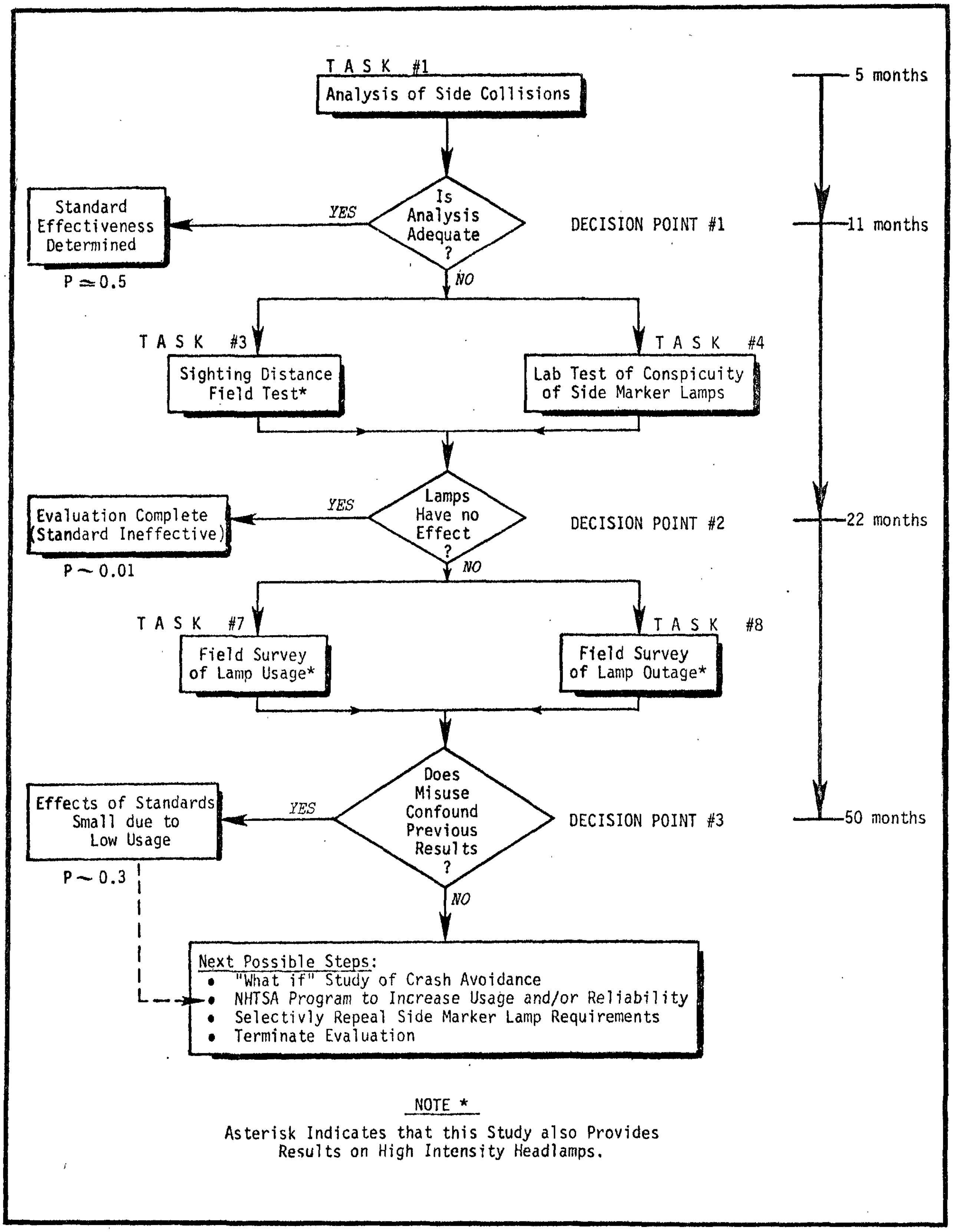

Figure 2-1. Flow chart for proposed evaluation of FMVSS 108: Side Marker Lamps.

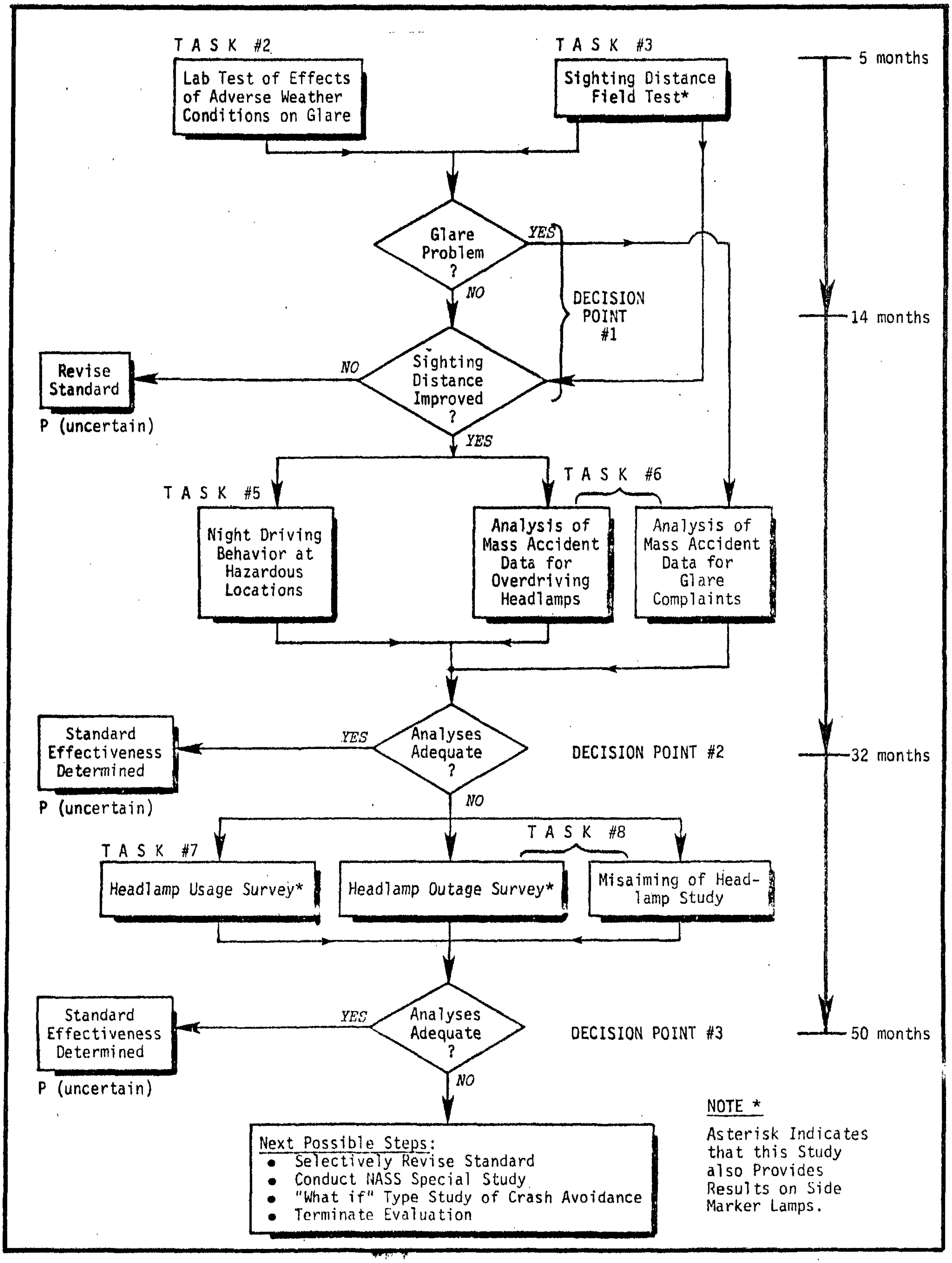

Figure 2-2. Flow chart for proposed evaluation of FMVSS 108: High Intensity Headlamps.

SIDE MARKER LAMPS

Task #1: Analysis of Side Collisions

Using existing mass accident data, this Task will attempt to determine the effectiveness of side marker lamps in reducing accidents during nighttime and other conditions of reduced visibility. This Task is the most direct assessment of the effectiveness of side marker lamps; however, based on a previous study, the expected effectiveness is small.

Decision Point #1

At the end of Month 11, NHTSA will have to decide whether the Analysis of Side Collisions adequately determines the effectiveness of the side marker lamps. CEM's initial estimate is that the probability of ending the evaluation at this point is one-half. The uncertainty is largely a product of determining a small effect in a large but nonetheless finite data base. If the results of the analysis are inadequate, NHTSA should proceed with the complementary studies included in Task #3 and Task #4.

Task #3: Sighting Distance Field Test*

In the early part of this Task, the effect of side marker lamps on visibility of vehicles will be determined in field tests. Because of artificiality introduced by the testing procedure, this Task will establish the potential effect of side marker lamps in improving visibility rather than the actual effect in crash avoidance.

Task #4: Laboratory Test of Conspicuity of Side Marker Lamps

This Task complements Task #3 in that it will provide more detail on the effects of different types of side marker lamps (integral, separated, intensity of light, area of lamp, etc.). This test is under laboratory rather than field conditions; therefore, one could not make general inferences from this study alone. However, this study will establish if there are differences in conspicuousness between side marker lamps.

Decision Point #2

At the end of Month 22, NHTSA will know whether there are significant differences in sightability due to side marker lamps. It is CEM's estimate that it is highly likely that some effect will be found at least under certain

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*This Task also helps evaluate high intensity headlamps.

conditions. At this point, NHTSA should also reevaluate the initial study on side collisions. If the results of Tasks #3 and #4 contradict the results of Task #1 (i.e., side marker lamps have an effect in the laboratory tests but one cannot find an effect in accident reduction) then one must go on to Task #7 and Task #8 to learn more about the actual use of side marker lamps.

Task #7: Field Survey of Lamp Usage*

This Task concentrates on the question of whether and when side marker lamps are being used. If the lamps are not being used when they might be most effective, then one would understand the apparent contradiction encountered earlier.

Task #8: Field Survey of Lamp Outage*

This Task is complementary to Task #7, as it addresses another possible reason for the non-usage of side marker lamps. The source of this information is primarily from the examination of vehicle defect records in various states and observation of vehicles selected for the headlamp misaiming study (the other subtask in Task #8).

Decision Point #3

At the end of Month 50, NHTSA will have to decide whether the results of Task #7 and Task #8 show that usage factors confound the problem of estimating the effectiveness of the side marker lamps. CEM's estimate is that the probability is low ($p \approx 0.3$) that usage effects will confound the results of the evaluation.

Next Possible Steps

If none of the above analyses determine the effectiveness of side marker lamps, then there are several possible steps NHTSA might undertake. One is to do a retrospective study of accidents to see what would have happened if side marker lamps had been involved. The results of Task #7 and Task #8 might indicate that a program to increase usage and/or reliability of side marker lamps is desirable. If the analyses show no effect of side marker lamps, NHTSA might endeavor to selectively repeal certain requirements for side marker lamps. During any repeal program, accident trends should be monitored to warn of any adverse impacts. A final alternative is to terminate the evaluation.

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*This Task also helps evaluate high intensity headlamps.

HIGH INTENSITY HEADLAMPS

Task #2: Laboratory Test of Effects of Adverse Weather Conditions on Glare

This Task is a relatively straightforward experiment directed at concerns raised in the NHTSA Docket files with regard to dispersion of light from the surface of the headlamp. If light is widely scattered, there is the possibility that under certain environmental conditions there will be backscattering and glare.

Task #3: Sighting Distance Field Test*

This field test addresses the basic questions relating to high intensity headlamps: (a) How much do they increase visibility? (b) How much do they increase glare (and thereby reduce sighting distance)? These tests are done under controlled field conditions using volutneer drivers and specially prepared vehicles on a standard off-road track under closely monitored light conditions. This test will determine the potential differences between the regular and high intensity headlamps. This test cannot be directly translated into on-highway performance.

Decision Point #1

At the end of Month 14, NHTSA will have to consider several alternative decisions depending on the results of the initial studies. One possibility is that glare is a potential problem. In that case, NHTSA should initiate an analysis of mass accident data for glare complaints (Task #6). Another possible result is that sighting distance is significantly improved. In that case, NHTSA should initiate programs to evaluate the effect of that in actual circumstances, analyzing night driving behavior at hazardous locations by observation (Task #5) and also analyzing mass accident data for accidents where overdriving the headlamps may have been a significant factor (also Task #6). If the results of the first two studies have been negative, i.e., no significant difference in glare or sighting distance, NHTSA could decide to revise the Standard. CEM is uncertain of the likelihood of this negative result because of the degree of judgment involved in determining whether the effect is substantial or not. Calculations indicate that high intensity headlamps may only increase sighting distance 10 to 20 percent on high beam. And high

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*This test also helps evalute the effectiveness of side marker lamps.

beam usage is only a small fraction of total headlamp usage. Therefore, it is unclear whether NHTSA will consider a revision.

Task #5: Night Driving Behavior at Hazardous Locations

Because of the small potential effect of the high intensity headlamps and their relatively slow rate of introduction (because they are a manufacturer-determined feature), the studies evaluating the effects of high intensity headlamps in real world situations are speculative. This Task outlines a study which will directly test the hypotheses that the high intensity headlamps are providing drivers with better information sooner by studying their behavior in selected highway areas where night driving is difficult.

Task #6: Analysis of Mass Accident Data for Overdriving Headlamps and Glare Complaints

Because the skills and data bases for these studies overlap, they have been combined into one Task. They are kept separate in the flow chart to reflect the fact that different potential effects of the high intensity headlamps are being examined. Although it is not shown within the flow chart (but is shown on the Gantt chart in Section 5), these analyses could be repeated at a later date if the evaluation is still continuing.

Decision Point #2

At the end of Month 32, NHTSA can review the results of the analyses which looked at real world performance and decide whether these analyses, combined with the results of the earlier tests, adequately determine the effectiveness of the high intensity headlamps. Because of the speculative nature of the analyses, CEM is uncertain of the likelihood of adequately determining high intensity headlamp effectiveness. If the analyses are not adequate, NHTSA should proceed with studies which expand the knowledge about actual headlamp performance in the field by surveying usage, outage, and misaiming (Tasks #7 and #8).

Task #7: Headlamp Usage Survey*

This Task would try to determine if the reason for failing to find any effect of high intensity headlamps is due to the fact that they are seldom used on high beams, or people who use them consistently driver faster, etc. These results might explain the results previously achieved.

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*This Task would also help determine the patterns of side marker lamp usage.

Task #8: Misaiming of Headlamps and Light Outage Survey

This Task has two subtasks. The primary subtask is to conduct a study of headlamp misaiming through careful measurements of headlamps of vehicles selected from the current motor vehicle population. The second subtask is to determine the light outage rate of the current motor vehicle population based on those selected for the misaiming study and state motor vehicle inspection and other similar records. The purpose of this Task is to determine if there are some consistent differences between high intensity and regular headlamps which can explain and perhaps revise the results encountered so far in the evaluation program.

Decision Point #3

At the end of Month 50, NHTSA will be able to review the results of all of the above Tasks to determine whether the analyses have adequately determined the effectiveness of high intensity headlamps. CEM is uncertain what the likelihood of success is because of the great uncertainty about the number of vehicles which will have high intensity headlamps* and the potentially minimal effect they will have on sighting distance.

Next Possible Steps

The reasons for the failure to adequately evaluate the effects of high intensity headlamps will affect the choice of the next steps. One option is to try to revise the Standard on a selective basis so that one knows the size of the potential effect and can look at the differences in accidents between selected car populations. Another option is to conduct a NASS Special Study of nighttime accidents. A third possibility would be to use detailed accident data to estimate "what would have happened if" cars had had high intensity headlamps. A final possibility is to terminate the evaluation program.

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*As noted earlier, NHTSA has proposed a new revision to FMVSS 108 which would allow higher intensity headlamps of standard dimensions (the 5 and 7 1/2 circular and small rectangular sealed beam units).

3.0 EVALUATION PLAN

3.1 Analysis of Side Collisions

3.1.1 Introduction

The purpose of this analysis is to estimate the effectiveness of side marker lamps in reducing the frequency of side collisions during darkness or other periods of reduced visibility--dawn/dusk/rain/snow/fog.

This analysis is an expansion of an earlier CEM study of FMVSS's which estimated about a one percent effect of side marker lamps in reducing side collisions during nighttime [1]. This analysis will examine those particular situations--dawn/dusk/rain/snow/fog--where the effects of the side marker lamps should have their greatest effect. (This result should be partially confirmed by some of the results of the sighting distance experiment, Section 3.7.)

3.1.2 Data Requirements

The basic factors to be considered in the analysis include the drivers (particularly the driver of the striking vehicle), the vehicles, the ambient environmental conditions, the highway characteristics and perhaps the traffic conditions. The specific variables for the two-car side collisions include:

- Drivers
  - Age
  - Sex
  - Visual Restrictions (if indicated)
  - Alcohol Involvement (speculative)
- Vehicles

- Struck/striking - Make - Model - Model year	leads to	- Side marker lamps - Vehicle size - Brakes (speculative effect for the striking vehicle)

  - Color (speculative)
- Ambient Conditions
  - Time of day (by hour)
  - Weather conditions (snow/rain/fog)
- Highway Characteristics
  - Intersection (controlled/uncontrolled/ etc.)
  - Highway type (Primary, secondary/etc.)
  - Location (Rural/urban/land use/etc.)
  - Surface type (speculative, perhaps not available)
  - Illumination (if indicated; however, it might also be inferred from type of intersection, highway and location)
- Traffic Characteristics (speculative)
  - Type of traffic - i.e., commuter - might be inferred from highway characteristics, time of day, etc.

3.1.3 Data Acquisition and Preparation

Accident data tapes will be acquired and processed in order to obtain two sets of information:

- Side collision data set where a passenger car is struck.
- Alternative accident involvement measures.

In order to estimate the exposure of the vehicles in side collisions, several measures should be developed.

1. Registration data by model year and calendar year. This might be modified based on VMT estimates for different age vehicles.
2. Accident involvement rates by model year and calendar year. Some alternative rates might be:
    a. Vehicles struck daytime
    b. Vehicles struck nighttime
    c. Vehicles in non-side collisions
    d. Vehicles struck in side during daytime.

The accident data should be processed to reduce the number of irrelevant cases and variables to be analyzed. Also, the data should be processed to provide some basic counts. The first set of counts is based on all accidents and tabulates the number of vehicles by model year. The second set of counts would be based on side collisions. The side collision data would be the set of data to be analyzed in detail.

The sources of accident data include mass accident data from Texas, North Carolina, and New York for 1968-1974*. Reported accidents in these states amount to 400,000, 125,000, and 430,000 respectively in 1970.

3.1.4 Preliminary Results

A previous study of effectiveness of FMVSS estimated that side marker lamps reduced the frequency of right angle collisions involving passenger cars by between 0.5 and 1.0 percent [1]. This result was based on a study of two-vehicle collisions in Texas in 1971. The relative frequency of accidents for three lighting conditions (day, night, dawn/dusk) were derived for the struck vehicles by model year. Day/night exposure changes with vehicle age. The 1971 accident data indicate a break in this age trend with the 1968 model year; the 1972 data do not suggest such a break. Dividing the number of cars struck in side crashes

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*We recommend the use of the 1968-1974 period as the minimum to be examined because of potential effects related to age, such as vehicle exposure, etc. If one focused solely on those years directly following the introduction of side marker lamps, there is the potential of ascribing a reduction in side collisions to the lamps when the reduction might be a function of the vehicles being new.

by the number registered showed a stable trend for day accidents by model year. Night crashes showed a less clear picture. The curve of the relative frequency of night crashes suggests either a slight reduction in the frequency of such accidents beginning in Model Year 1968, or it might have been just an age trend with larger fluctuations.

In New York in 1970, of 430,000 reported accidents, 65,000 were two-vehicle angle collisions at intersections (15 percent). Of all accidents, 25 percent occurred between 8 PM and 6 AM. An additional 5 percent occurred between 6 and 8 in the morning and almost 20 percent occurred between 5 and 8 in the evening.* An examination of North Carolina statistics reveals a similar distribution of nighttime accidents (26 percent) and angle collisions at intersections (16 percent). Neither state reported the distribution of vehicle ages, but in New York in 1976, of the vehicles involved in accidents, 7 percent were the current model, 18 percent were one or two years old, 29 percent were three to five years old, and 27 percent were six to nine years old. Therefore, of perhaps seven million accidents in 1968 through 1974 from New York, North Carolina and Texas, approximately 65,000 will be nighttime side collisions involving Post-Standard models.** During dawn/dusk and other periods of reduced visibility, an almost equal number of side collision accidents involving Post-Standard vehicles would occur.

3.1.5 Analysis

The analysis of side collisions will follow the flow diagram shown in Figure 3-1. The overall thrust of this analysis is to examine an adequate data base of side collision accidents to determine if the side marker lamps have had any effect in reducing the frequency of such accidents at night or during other periods of reduced visibility. A secondary point will be to test whether the effect of the side marker lamps depends on the lamp characterisitics (basically integral or separate side marker lamp elements) or some other vehicle characteristics.† It is strongly suspected that the effectiveness of the side marker lamps will be greatest during dawn/dusk/and other periods of reduced light levels--at night the effect of the side markers will probably be overshadowed by the effect

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*Many early-evening accidents involve drivers who have been drinking.

**7,000,000 accidents x 15 percent angle collisions at intersections x 25 percent nighttime x approximately 25 percent Post-Standard vehicles involved in 1968 through 1974 accidents = 65,000 accidents.

†These results will be related to the laboratory study of the Conspicuity of Side Marker Lamps (Section 3.10).

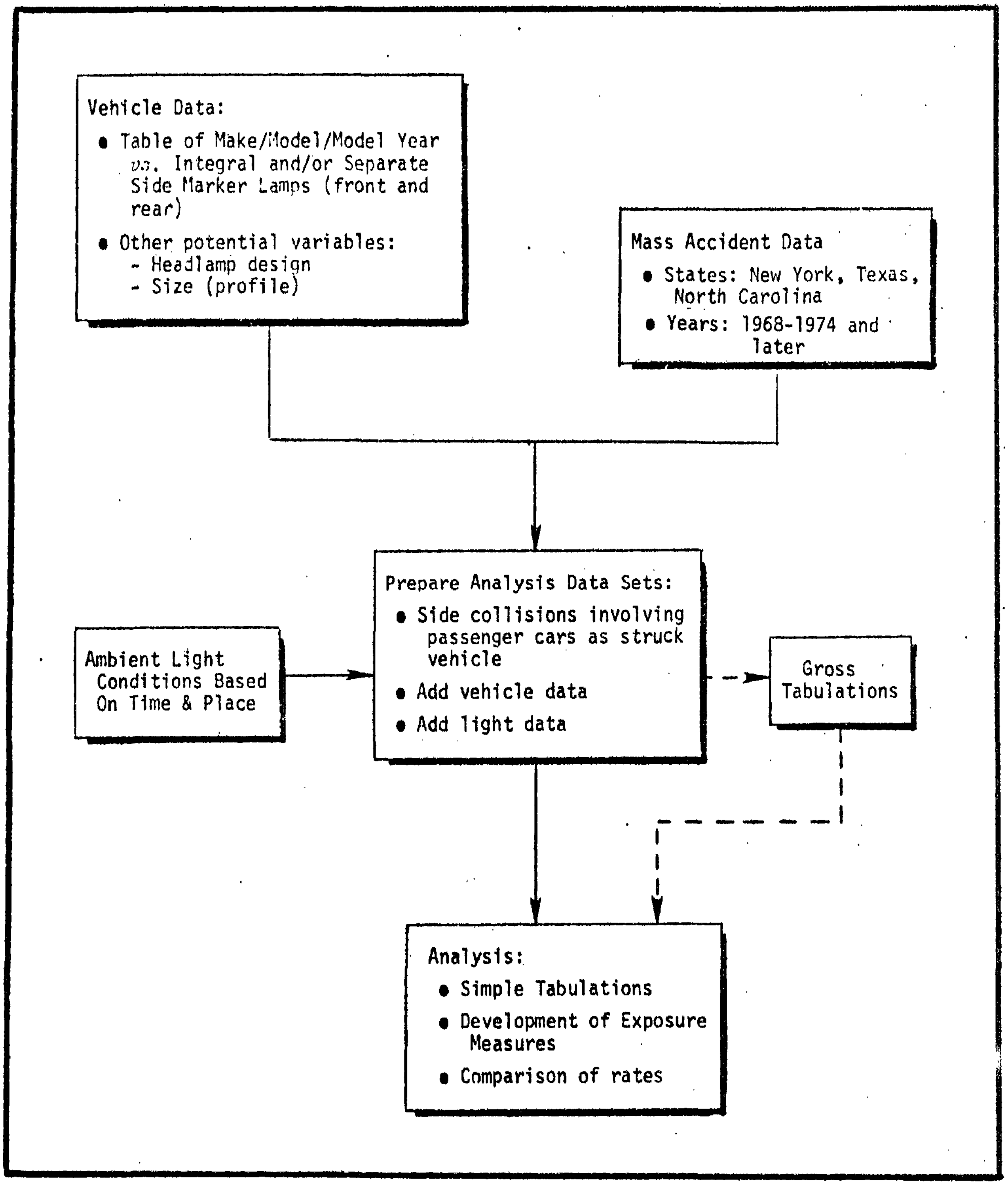

Figure 3-1. Outline of the Analysis of Side Collisions.

of the headlamps.[*]

Analysis of the side collisions will follow these steps:

- Vehicle Data. A review of the literature on new passenger cars will be conducted to obtain information on the front and rear side marker lamps and other vehicle features. Data will be recorded for 1968 through 1974 model vehicles. The vehicles selected should include the most popular make/model combinations offered during those years. Correspondence lists should be made between these make/model combinations and the make/model variables used in the accident data--Texas and New York have different variables codes for makes and models. The variables would include whether the front or rear side marker lamps were integrated or separate from the front or rear lighting group, and even if they are separate, whether the front or rear lighting fixtures are visible from the side. Secondary information would include the headlamp design characteristics (whether the vehicle design prevents viewing from the side) and measures of the height and length of the vehicle, size of side markers, reflectors, etc.
- Ambient Light. For the time and geographic location of the accidents there is an average light level. A table or perhaps a function would be used to describe the light level by time and place. (Texas and New York will have to be divided in half because of their size.) However accident time may not be accurately recorded.
- Prepare Analysis Data Set. The preparation of the side collision analysis data set will include the extraction of the cases of side collisions where the struck car was a passenger vehicle. Vehicle and ambient light condition data will be appended to these cases. At the same time the side collision data are extracted, certain gross tabulations of the overall accident data base will be prepared.
- Gross Tabulation. Several separate and aggregate tabulations of the data on the accident tapes will be prepared for comparison to the side collision accident data. These tables will include:
  - For all accidents: accident involvement by model year x time of day (hour).
  - For single vehicle accidents: accident involvement by model year x time of day for passenger cars, trucks and buses, and other vehicles.
  - For front-to-front, front-to-side, and front-to-rear accidents, where a passenger car is struck: accident involvement of the struck and striking car by model year x time of day (hour).
  - For other types of collisions: accident involvement of passenger cars, trucks and buses, and other vehicles, by model year x time of day (hour).

  Additional tabulations may be prepared later in the analysis if certain variables seem to be significant, such as ambient light.

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[*] This assumption will be tested in the Sighting Distance Experiment (Section 3.7).

- Tabulations of Side Collision Data. The side collision data should be studied with regard to rural *vs.*urban accidents, accidents at lighted *vs.* unlighted intersections. Alcohol involvement on the part of either driver may interfere with the effect of the side marker lamps. Time of day may present a less clear relationship than the distribution of side collisons (by model years of struck vehicle) *vs.* the ambient light condition.

In order to estimate the reduction in side collisions for cars equipped with side marker lamps, some relative measure has to be developed. A measure often used in ratio comparisons is the number of registered vehicles. It is assumed that this number represents the exposure of these cars to accident situations. This ratio can be modified by adjusting registration data for mileage estimates based on the age of the vehicle. However, the kind of accident situations a driver and vehicle are exposed to may not be directly related to the absolute amount of exposure estimated in miles. Therefore other measures of exposure might be derived. The denominator of the ratio may be the number of vehicles (by model year) involved in accidents which have no relation to side marker lamps--for instance the number of vehicles involved in daytime side accidents. If one wanted to do the comparison on an hour-by-hour basis, the ratio could be side collision involved vehicles (by model year) to rear ended vehicles at nighttime.

Another more speculative, approach could eliminate the comparison to other vehicles entirely. In this approach one would assume a stable exposure pattern for one-year-old cars, for two-year-old cars, etc. throughout the day. This could be determined by plotting the frequency of side collision involvement *vs.* time of day for the same age vehicle in different accident years. If the side marker lamps have any effect, the frequency distribution of the models struck in side collisions for one-year-old, two-year-old, etc. will be different for Post-Standard vehicles. See Figure 3-2 below. This last approach is more speculative beause the pattern of exposure may be far from stable.

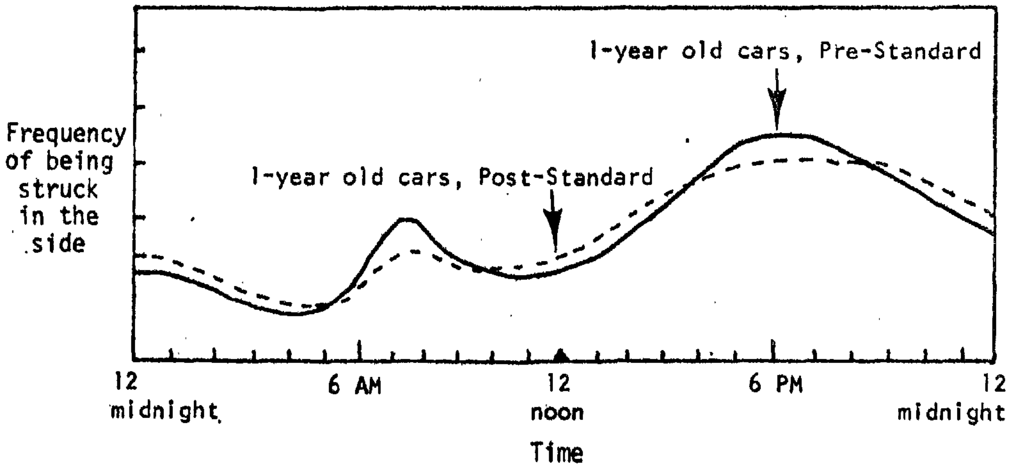

Figure 3-2. Hypothetical frequency distribution of one-year old Pre- and Post-Standard vehicles being struck in the side.

Another possible effect to be studied is the differential effect of different side marker lamp configurations, that is, are the side marker lamps which are separate from the front or rear lighting groups more or less effective? Also, is uniformity of height of front and rear side marker lamps significant? The entire analysis should be repeated using adverse weather conditions instead of dawn/dusk as the time to expect the greatest effect.

Since the changes in rates to be expected are small we expect that sample sizes needed to show an effect will be large. For right angle collisions, the change is from about 13 to 14 percent occurring at night for Pre-Standard vehicles to about one percent less than this for Post-Standard vehicles [1].

Let the true Pre- and Post-Standard proportions be $P + \varepsilon$ and $P - \varepsilon$ respectively, where the difference between these proportions, 2ε, is about 1 percent. Then for P much greater than 2ε, say P larger than 10 percent, the sample size necessary to determine an effect with level α and power β is given (after some manipulation of the results) in Fleiss [15, pp 29-30] by

$$n = (z_{1-\alpha/2} + z_{\beta})^2 \frac{P(1-P)}{2\varepsilon^2} + \frac{2}{\varepsilon}$$

where z_p is the $100p'^{th}$ percentile of the standard normal distribution, and the $2/\varepsilon$ term is the contribution from continuity corrections. For $\alpha = 0.05$, $\beta = 0.95$ and $\varepsilon = 0.005$ (0.5%) this gives:

$$n = 64800 \times \{4P(1-P)\} + 400$$

For P less than 0.146, the term $4P(1-P)$ is less than 0.5 so that

$$n \leq 32800.$$

This number of cases is required for the Pre-Standard and Post-Standard vehicles separately. This number is large for two reasons: the change 2ε is small, and the power β is very high. With the worst case power, $\beta = 0.5$, and $\alpha = 0.05$, and $\varepsilon = 0.005$ as before,

$$n \simeq 19200 \{4P(1-P)\} + 400$$

so that with P less than 0.146,

$$n \leq 10000.$$

This value for n is then a lower bound on the size of any sample to be analysed. Of course, if the effect of the Standard is larger than assumed here, smaller sample sizes will be adequate.

3.2 Overdriving Headlamps

3.2.1 Introduction

This is a speculative approach for evaluating the effects of high intensity headlamps. The purpose of this study is to estimate the frequency of nighttime accidents where overdriving headlamps probably occurs and to estimate the reduction th the frequency of such accidents for those vehicles equipped with high intensity headlamps.

This study will use primarily mass accident data from several large states. Since significant numbers of vehicles with high intensity headlamps do not yet exist in the accident population, this study will have to be delayed until at least 1980.

Several types of nighttime accidents where headlamp illumination is a factor are accidents on main rural roads (unilluminated) where an object is struck--perhaps a pedestrian or possibly an animal.

3.2.2 Data Requirements

For the analysis of accidents involving overdriving the headlamps, data will be required in the following basic areas: driver, vehicle, (possibly) social context, ambient environment, highway environment and (possibly) traffic conditions. Specifically, the variables include:

- Driver
    - Age
    - Sex
    - Alcohol involvement or driver asleep (if recorded)
    - Visual restrictions (glasses if recorded).
- Vehicle
    - Make/Model/Model Year
    - Headlamp type (high intensity or regular)
    - Vehicle defects (headlamp or other defects).
- Social Context
    - Day of week
    - Time of night (tiredness a factor in later hours)
    - Holiday (increased potential alcohol involvement).
- Ambient Environment
    - Weather conditions (rain/snow/fog).

- Highway Environment
  - Local (rural/urban)
  - Type of highway (interstate, main road, secondary, local, etc.)
  - Grade, curvature, intersection

- Traffic Conditions (speculative factor)
  - Traffic volume.

A variable which would be desirable is travel speed before the collision. Mass accident data generally contain some estimates of this but these estimates are highly questionable. Another potentially significant variable which is largely unobtainable from mass data is highway demarcation -- road markings, guard rails, reflectors, trees, etc.

3.2.3 Data Acquisition and Preparation

The suggested data sources for this study are the same as for the previous study (of side collisions). They are Texas, New York, and North Carolina mass accident data. However, this study will have to wait until at least the 1979 accident data files are compiled because significant numbers of vehicles equipped with high intensity headlamps will not be available until then. In addition to the 1979 data, some earlier data (1975 on) would also be needed to estimate trends and stability of these certain types of nighttime accidents.

3.2.4 Preliminary Results

Assuming that a "safe speed" is the maximum speed from which a driver could safely brake his vehicle to avoid striking a standardized dummy, then a great majority of vehicles exceeded an empirically derived "safe speed" for that highway in a 1968 study of headlamp beam usage.* Hare and Hemion found that high beam usage was about 25 percent of open road situations and in most of these cases the driver did not exceed the "safe speed" [3]. However, in other cases where low beams were used, a minimum of 75 percent of the drivers exceeded the safe speed, with higher percentages for wet roads or cases of oncoming traffic.

The high intensity headlamps have double the candlepower of the regular headlamps. However, twice the candlepower does not result in doubling of the distance an individual can see because the visibility of an object depends on its illumination and reflectance of light back to the observer. In the simplest case, a doubling of candlepower increases the distance of sighting by only 19 percent.

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* A repetition of this study with certain additions is suggested to update and broaden the knowledge on lighting system usage (Section 3.5).

EXAMPLE: A reflector at distances D feet from headlights of candlepower, CPH, is therefore illuminated by CPH÷D^2 foot-candles. The driver's eyes at distance D feet from a reflector of candlepower, CPR, are illuminated by CPR÷D^2 foot-candles. The specific intensity of a reflector, SI, is the ratio of the candlepower one reflector gives off, CPR, to the illumination it receives, CPH÷D^2. SAE Standard J594c covers reflex reflectors and the minimum specific intensity is 9.0 for an amber reflector illuminated straight on and viewed from a very small angle, 0.2 degrees, from the source of illumination. In summary, the signal at the eye is equal to $\frac{SI \times CPH}{D^2}$. Therefore for the same intensity reflector a doubling of headlamp candlepower will lead to an improvement in sighting distance equivalent to the fourth root of 2, about 19 percent (Example adapted from [2].)

However, this theoretical increase in maximum sighting distance is not achievable because the low level of illumination and reduction in the size of the image to be sighted causes visual acuity to be a factor. Since headlamps are generally used on low beam and even the high beam effect of the high intensity headlamps is not as overwhelming as the increase in candlepower, therefore the effect of the high intensity headlamps in avoiding accidents will probably be small.*

3.2.5 Analysis

The analysis of nighttime accidents where overdriving of headlamps is suspected as a critical factor would follow the schematic presented in Figure 3-3.

The first task after obtaining the accident data is defining specific nighttime accident situations where overdriving headlamps is probably a significant factor. As mentioned before single vehicle nighttime accidents where an object in the highway is struck is one potential accident type and running off the road on a curve is another. However, for each state--New York, North Carolina, and Texas--different codes are used on their accident data tapes. Therefore, for each state specific definitions of an accident type will be different.

Initial processing of the mass accident data tapes should be conducted for a number of reasons. The first is to produce a reduced edited set of data for analysis. Often this is necessary because states record their data in a form which is not compatible with efficient computer processing. Thus, reformatting

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*If the analysis shows no effect of high intensity headlamps a conclusion which might be drawn is that automobile manufacturers may have introduced a significantly more expensive high intensity headlamp, without a proportionate increase in effectiveness.

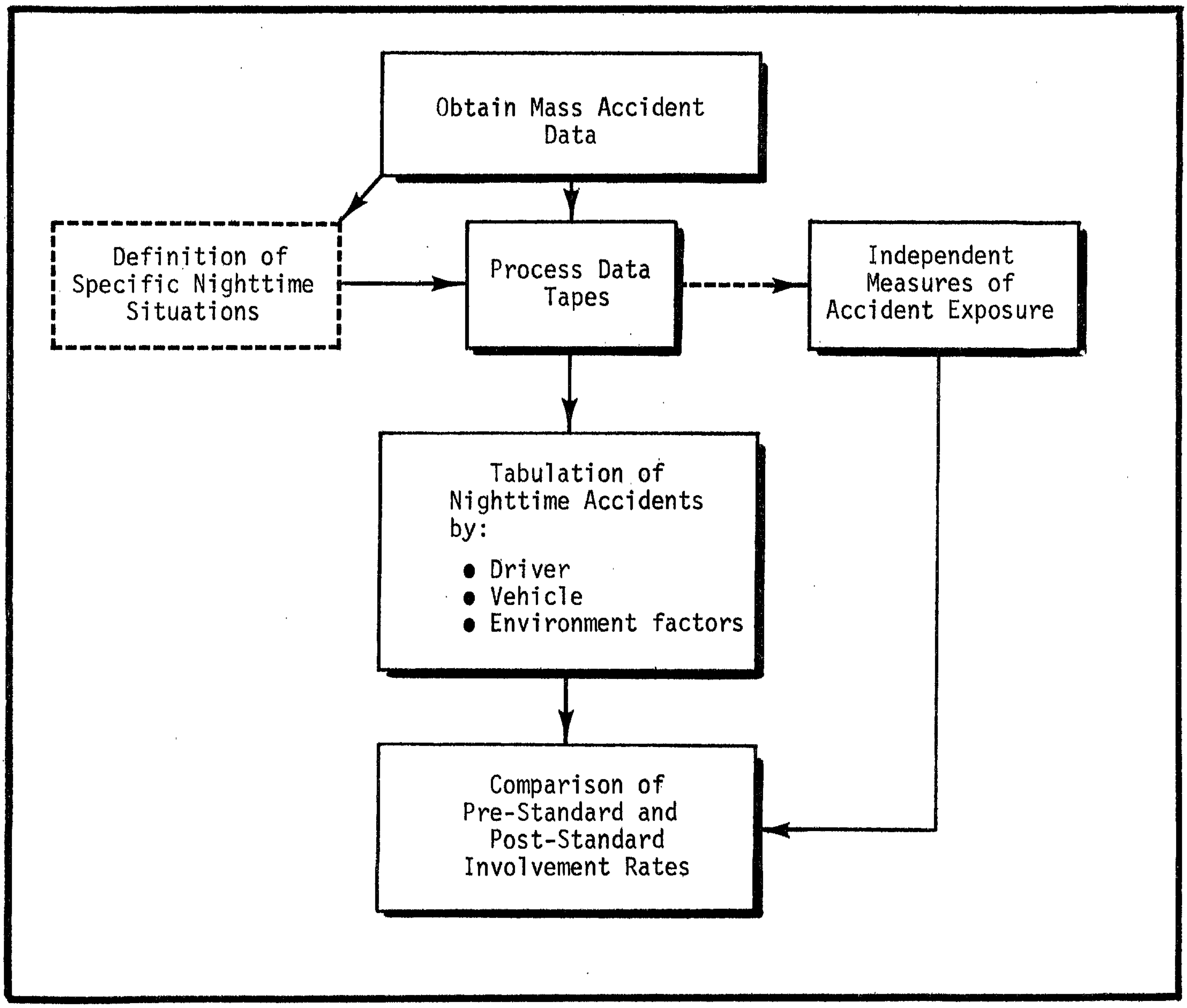

Figure 3-3. Analysis of nighttime accidents involving overdriving headlamps.

of the data is often desirable for later computational efficiency. A second reason for initial processing is to get gross tabulations of data on other types of accidents for involvement which would be relatively unaffected by the high intensity headlamps, such as being struck in the side or rear at night.

Since only some new models in 1978 and more in the 1979 model years will have high intensity headlamps, there is little reason to believe that the actual driving exposure will differ markedly between comparable new cars with and without these lamps. Therefore, registration data might be sufficient to use as an exposure base. However, there may be strange interactions between the new vehicles with high intensity headlamps and their particular types of accidents or exposure patterns. Therefore another measure of accident exposure might be the numbers of these vehicles struck in nighttime accidents.

The data set of nighttime accidents should be processed to provide more detailed tabulations. Driver, vehicle and environmental factors would be tabulated to determine if there are gross differences between the high intensity headlamp vehicles and others in these accidents. However, the initial tabulations are exploratory in nature.

The comparison of the accident rates of high intensity headlamp vehicles versus regular intensity vehicles would be done for given accident situations, e.g., adverse weather conditions, runoff-the-road at a curve. A base of the ratio could be registration data. Another base could be unaffected nighttime accidents. These ratios would be examined for several years of data to see if there is a trend toward certain types of accidents for older cars of whether differences can be attributable to the high intensity headlamps.

3.3 Glare Complaints

3.3.1 Introduction

The purpose of this study is to estimate the increase in accidents due to the glare blinding from high intensity headlamps.

This analysis will try to estimate a potentially negative aspect of the high intensity headlamps, that is, the blinding of other drivers. This analysis is speculative because of the questionable reliability of reports of glare and stability of that data and the slow introduction high intensity vehicles will have in the vehicle population. Hemion reported glare involvement ranging from one-half to four percent of nighttime accidents in rural areas [4]. This study will investigate the trend of glare complaints in accidents in specific large states for several years to estimate if any change in the trend might be due to the influx of vehicles with high intensity headlamps. Secondly there will be a cross-sectional analysis--comparison of glare accident ratios in different areas of these states--to see if the level of glare complaints corresponds to the level of high intensity headlamp vehicles in the area.

3.3.2 Data Requirements

The basic factors which will have to be considered relate primarily to the driver, the vehicle (possibly) and the highway environment. Because the glare is caused by some other vehicle (or possibly some other source) than the accident vehicle, the study will not have any direct measure on vehicles with high intensity headlamps causing glare complaints.* The specific variables for these glare complaint accidents include:

- Driver
  - Age
  - Sex
  - Visual restrictions (if indicated).
- Vehicle

  (A speculative effect would be due to the seating height in the vehicle.)
- Highway Environment
  - Wet highway
  - Highway lighting
  - Type of highway (interstate, primary, secondary, local)
  - Locale of highway (rural/urban/residential/etc.)
  - Illumination

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*The lighting system usage survey will try to ascertain if the glare level from high intensity lamps receives more "complaints", (i.e., requests for dimming) from oncoming vehicles (Section 3.5).

3.3.3 Data Acquisition and Preparation

Accident data tapes will be required from several states. Both Texas and New York are two large states which presently encode data on glare; therefore, using data tapes from these states would be desirable. North Carolina does not presently collect information on glare complaints. Other large states which do collect information on glare complaints in traffic accidents are Virginia and Florida; however, if the analysis of glare complaints is combined with that of overdriving headlamps (Section 3.2) one would restrict the analysis to Texas and New York.

The accident years to be used include 1975 through 1979.

3.3.4 Preliminary Results

A 1969 study listed reported glare involvement for six states [3]. These results are shown below in Table 3-1. This table shows two things: (a) the low incidence of glare involvement in accidents--a few percent of night accidents, and (b) an apparent instability of the phenomenon--e.g., compare Montana 1965 and 1966. However, based on some simple calculations, the probable numbers of accidents represented by the Montana entries are on the order of 5 accidents.* Looking at more recent data from New York, glare as an apparent contributing factor has been a constant 0.3 percent of all accidents in 1976 and in the first six months of 1967 (1,725 and 842 accidents, respectively). Before 1976 such data was not reported in annual reports by New York and is not reported by Texas; however, both states have collected this data over a considerable period, at least from 1970.

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*Because the raw data from Montana were not available, rough calculations were based on a comparison to New York State in 1966. In New York they had 2,738 fatalities and 445,363 reported accidents in 1966. Montana had 276 traffic deaths. Therefore, if Montana had the same reporting requirements as New York, approximately 46,000 accidents would have been reported. Of the 455,363 New York accidents, 1,369 were on unlit rural roads. Thus, of the 46,000 Montana accidents, approximately 140 would have been on unlit rural roads. Since Montana is much more rural and sparsely populated than New York, that number may be several times larger. However even if there were 500 such nighttime accidents on unlit rural roads, 1 percent would yield 5 accidents. Therefore, the variability of Montana is probably more effected by smallness of the sample than glare blinding.

TABLE 3-1

REPORTED HEADLIGHT GLARE INVOLVEMENT IN ACCIDENTS
(Percent)

State	All Accidents	All Night Accidents	All Fatal Accidents	Accidents on Unlit Rural Roads	Accidents on Lit Urban Roads
Arizona	-	3.8	1.5	-	-
Florida	-	0.2	-	0.4	0.7
Maine	0.9	-	-	-	-
Montana '65	-	0.92	-	1.05*	-
Montana '66	-	0.35	-	0.66*	-
New York	-	1.8	-	4.27	-
Virginia	-	0.24	-	0.53	-

Source: Hemion [4].

*See above discussion of Montana values.

A second preliminary result is the fact that the drivers over the age of 40 have a markedly greater susceptability to glare [5].

In summary, it seems apparent that there will be several thousand glare involved accidents per year for New York and Texas and that these accidents will be biased toward older drivers.

3.3.5 Analysis

The analysis of glare involvement in nighttime accidents will generally follow the flow diagram shown in Figure 3-4. The overall purpose of this analysis is to test whether there is any increase in the rate of glare involvement accidents which might be directly attributable to the increased number of vehicles with high intensity headlamps. A secondary aspect is with regard to driver and highway characteristics.

This approach is speculative for several reasons: low rate of introduction of high intensity headlamps, low incidence of glare involvement, rate of glare should be affected by inspection programs and the density of night traffic on unlighted highways, reporting of glare depends on driver who may use it as an excuse, etc. Therefore, this analysis alone will probably not establish the negative effects of high intensity headlamps, but the information can be added to the results of the Sighting Distance Experiment see Section 3.7 and Misaiming of Headlamps in Section 3.9.

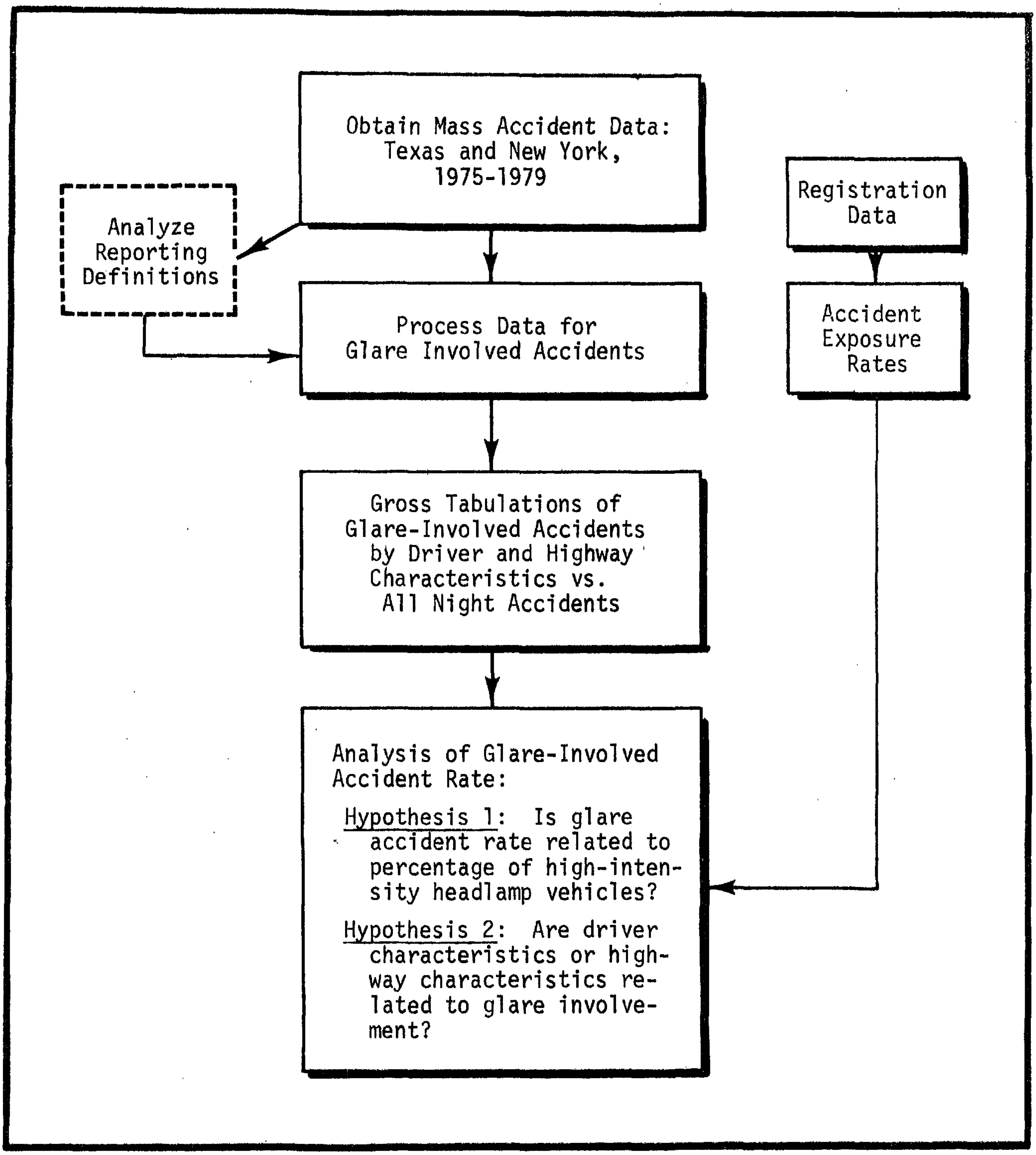

Figure 3-4. Analysis of glare involvement in accidents.

The approach to analyzing glare-involved accidents is as follows:

Obtain mass accident data for Texas and New York for 1975 through 1979. After obtaining this data one will have to analyze the different reporting definitions, that is, not only how they classify glare involvement, but also if any other coding or recording changes took place 1975 to 1979 which might affect the numbers of accidents or how they were recorded.*

It is desirable to process the basic data tapes to yield smaller, edited analysis data sets. At the same time these computer data bases are being reduced, it is desirable to prepare gross tabulations of the driver and highway characteristics of glare involved accidents versus all night accidents. An obvious result one expects is that glare involved accidents will occur more frequently on unlit rural roads. Another possible result is that older drivers will be more often involved in this type of nighttime accident.

Since the occurrence of these accidents is presumably based on the frequency of the high intensity headlamps on other cars, one need not be concerned (at least initially) with the type of vehicle involved in the glare accident.** However, the basic data tapes can provide an indication of the numbers of vehicles with high intensity headlamps on the road at night by recording the frequency which they are being struck in the side or rear. Presumably, the high intensity headlamps should reduce the number of times these vehicles strike unlighted slow moving vehicles or objects at night. Another measure of exposure would be the number of vehicles registered with high intensity headlamps. This would require a make/model breakdown of the registration files using some convenient indicator like the Vehicle Identification Number (VIN) or use of R. L. Polk data.

The gross tabulations would be basically 2-way or 3-way tables where one dimension would always be glare-involved accidents versus other accident sets, primarily night accidents. Other dimensions would be driver age, sex, and visual restrictions. For the highway characteristics, basic categorizations would be type of road, locale (rural, urban), lighting, etc. Another table

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*For N. Y. glare is currently classified as an "apparent contributing environmental factor;" for Texas, the factor is "vision obstructed by headlight or sun glare."

**In a last detailed analysis one might wish to investigate if certain types of vehicles, perhaps with low seating positions, are involved more often than expected.

might investigate time of the accident, presumably glare will be more frequent when the traffic is denser, however, it may be that later at night people fail to dim their headlamps.

The glare-involved accident rate will be examined in two respects:

- Is there an increase in glare involved accidents which might be attributable to an increase in the numbers of vehicles with high intensity headlamps?
- Are there driver or highway characteristics which are strongly related to glare-involved accidents?

The accident rate will be examined from two perspectives as a trend over time (trend analysis) and relative to high intensity headlamp vehicles in the area (cross-sectional analysis). In the trend analysis the basic question is whether the 1975, 1976, and first 9 months of 1977 show a stable trend of glare accidents and, secondly, whether a deviation from that trend corresponds to the introduction of high intensity headlamps, first on a few 1978 models and later on more 1979 models. The cross-sectional analysis focuses on the changes in rates in different areas of New York or Texas to see if these changes correspond to the changes in the mix of high intensity headlamp vehicles in those areas, e. g., larger changes in those areas with more registered high intensity headlamp vehicles.

3.4 Analysis of Vehicle Maneuvers at Hazardous Locations

3.4.1 Introduction

The purpose of this study is to evaluate whether high intensity headlamps have any effect on evasive or emergency manuevers (and accidents) at hazardous locations at night.

This study is of considerable relevance because it addresses the real world effects of the high intensity headlamps. The question is whether the vehicles equipped with these lamps react to the hazardous situation sooner (farther away). However, this study is also a considerable departure from typical accident analyses or controlled experimentation. The approach is basically to record via videotape the maneuvers of vehicles approaching a predetermined hazardous location at night. The hazardous locations will be determined primarily from highway department spot maps of accidents. The videotape records will be reviewed and the maneuvers of vehicles will be related to the type of headlamp.

3.4.2 Data Requirements

In a study of accident causation it would be desirable to have data in the following areas: driver, vehicle, social context, ambient environment, highway environment and traffic. Given that the data in this study is being collected from (recorded) observations of moving vehicles, the obtainable data is limited.

- Driver

  (No data is directly available).

- Vehicle
  - Headlamp type
  - Beam usage (high/low)
  - Speed (entering the hazardous location).
- Social Context
  - Time
  - Date (weekday/ weekend or holiday).
- Ambient Environment
  - Weather conditions
  - Ambient light

- Highway Environment
  - Type of hazardous location:
    - Sharp curve
    - Lane drop
    - Exit
    - Construction site
    - Other highway discontinuity
  - Type of highway
  - Maximum straightline distance hazard invisible
  - Markings/warnings.
- Traffic
  - Density of traffic (in the same direction and in the opposing direction)
  - Gap between the case vehicle and the preceding and succeeding vehicles.

The critical variable to be determined from the recorded observations is when, or how far from the hazard, did the case vehicle react.

3.4.3 Data Acquisition and Preparation

The data acquisition and preparation will have three major steps:

1. Identification of locations for data collection.
2. Data collection procedure development and execution.
3. Data extraction for analysis.

The identification of hazardous locations will be done primarily through examination of highway spot maps which show where accidents have occurred. Given a high density of accidents in a certain area these accidetns should have a high proportion of nighttime accidents. The main criterion for selection of a site for data collection is that the site have a relatively identifiable problem which might be helped by increased driver visibility. That is, an accident cause should not be obstruction of vision by billboards, overpasses or curves, but rather that there is a relatively straight protion of highway with a sudden discontinuity, an exit, a lane drop, a sharp curve. Even if these situations are well signed drivers should be able to see the signs and see the situation ahead better if they have high intensity headlamps. Finally, given that an area has fulfilled the above criteria--frequent accidents, nighttime accidents, vision related accidents--there has to be a way to observe the motorists. This last criterion has two parts, the observation team and equipment must have a vantage point in order to record the speed and motion of the vehicle as it approaches the hazardous location. Secondly, the observation team should not be located on the highway or in any other spot which would be hazardous to them and disturbing to the motorists. An ideal observation point would be from an overpass or the top of an embankment.

Highway departments are obviously concerned about hazardous locations like the type described above and they try their utmost to eliminate them. Therefore, another type of location which will be considered for this data collection are highway construction areas. Despite the fact that these areas may not yet have accumulated significant numbers of accidents, and despite the fact that they are often very well marked and lighted, these areas represent significant discontinuities in the highway environment requiring driver action, e.g., lane changing and/or braking. Therefore, these sites will also be considered for data collection.

The data collection procedures will require special teams to set up and operate mobile recording equipment at these hazardous locations. Vedeotape units with light intensifiers and speed monitoring equipment are the basic devices which will be necessary. The data collection should be synchronous with some timing device so that information from different sources can be compared. Ambient light measurement will also be collected so that results from this study can be compared with the sighting distance experiment (Section 3.7). The size of the effect of high intensity headlamps is unknown; however, one might assume their effect is proportional to the increased potential sighting distance--about 5 percent on low beam, 20 percent on high beam. Secondly, assuming an average daily traffic of 2,000 vehicles per day on a two-lane rural road and only a fraction of that occurring at night, then the rate of traffic past an observation site at early in the evening might be 50-100 vehicles per hour.* Assuming that the mix of vehicles simply follows registrations then in 1979 one might expect that 5 percent of the vehicles registered would have new headlamps.** This would mean only a few observed vehicles per hour would have high intensity headlamps. Therefore, data collection would have to take place

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*2,000 vehicles per day x 25 percent at night = 500 vehicles over a 12 hour period.

**In 1978 there are but a few models with the high intensity headlamps. According to the NHTSA Standard specialist, about one half the new cars in 1979 will have higher intensity headlamps [16].

at each observation point for several hours each evening and several evenings in order to collect significant numbers of higher intensity headlamp vehicles.* Data should be collected from several locations, at least 10.

The extraction of data for analysis would involve several steps. A detailed plan of the highway would have to be prepared so that the location of each vehicle maneuver can be recorded. Other information which will be extracted from the videotape includes the type of headlamps (high intensity headlamps have a unique large rectangular design)**, beam usage, and the presence of other vehicles--the behavior of a preceding vehicle may warn a following vehicle of a hazard or the presence of another vehicle could interfere with a driver reacting to a hazardous situation ahead. Another data element for each vehicle is the speed of the vehicle as it enters the hazard area. Data will be extracted from the videotapes and other records and coded for each high intensity headlamp vehicle and for a random sample of other vehicles. In other words, the videotape will first be reviewed to identify high intensity headlamp vehicles and information will be coded on these vehicles and then a random sampling will be made of other vehicles. The size of this random sample will be approximately the same size as the proportion of high intensity headlamp vehicles.

3.4.4 Preliminary Results

The methodology suggested in this study is very closely related to the traffic conflicts technique for evaluating accident potential. The traffic conflicts technique was developed for studying intersections and has been refined to apply to expressway merge areas [5, 6]. Currently, the National Cooperative Highway Research Program made a solicitation in May 1977 for a program which would further improve the traffic conflicts technique (Project Number 17-3). Therefore it seems that the technical procedures and experience are adequate for this type of study.

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*In order to get data on 50 high intensity vehicles would require 13.3 hours of observation--75 vehicles per hour at 5 percent high intensity vehicles yields 3.75 per hour.

**If glare prevents videotape identification of headlamp type, the audio part of the tape can be used to verbally make the identification on site.

3.4.5 Analysis

The analysis of the data derived from such a program would be relatively straightforward. One would analyze the distance from the hazard of first reaction by the driver, given headlamp type, beam usage, initial speed, and the presence of other vehicles. A variable which might have a potential effect would be ambient light; it also might be used to adjust results collected on different nights or different times of the night. The basic comparisons would be distance from hazard when action took place for regular and high intensity headlamps. This comparison would be made for different and aggregated condition--beam usage, initial speed, presence of other vehicle, type of hazard, ambient light, etc.

The analysis should first look at the absolute positions where action first takes place for any given hazardous location. Also, the relative distance between reaction, e.g., 5 percent farther for low beams, 20 percent for high beams, might be consistent for different hazardous locations.

The method of analysis is Analysis of Covariance (see Appendix B). The dependent variable is, for one analysis, how far the driver was from the hazard when he reacted. Headlamp type, beam usage, presence of other vehicles are the categorical factors, and initial speed is the covariate. Since many computer programs require a balanced design for the analysis of variance, another way of performing the analysis would be to set up the equivalent regression problem. *A priori*, it is impossible to determine confidence levels, etc., since not enough is known about the various effects. The suggested data collection procedure would sample 50 to 100 high intensity headlamp vehicles a week at each site; sampling at a minimum of 10 sites for one week, 500 to 1,000 vehicles is a reasonable number to expect. This will be enough to decide how much more data to collect, if it does not already give definitive results.

3.5 Lighting System Usage

3.5.1 Introduction

The purpose of this study is to provide data on the patterns of usage of headlamps and running lights.

This study will update and expand an earlier 1968 study which only focused on headlamp usage [3]. The question of running light usage is important in order to estimate the potential effect of the side marker lamps. For instance, if the side collision analysis (Section 3.1) reveals that side marker lamps reduce side collisions by 10 percent in the early evening hours, but the usage survey finds that only 25 percent of drivers have their lights on during these hours, then the potential effect of side marker lamps is much higher. Also, if the side collision analysis finds no significant reduction in side collisions in the early evening hours despite the fact that the sighting distance experiment (Section 3.7) shows that those are the hours side marker lamps are most conspicuous, then this study will reveal whether the reason for the results of the side collision analysis is lack of usage.

The information on headlamp usage is important because the increased potential sighting distance provided by the high intensity lamps is most significant when the high beams are used. This potential improvement may not be of much benefit if most driving is done on low beam, which is increasingly the case as areas become more densely populated and highways better lighted.

In summary, this study will not directly evaluate the effectiveness of side marker lamps or high intensity headlamps. This study will provide information on whether the potential effects of these safety improvements are limited by their under-utilization.

3.5.2 Data Requirements

This study has limited data requirements. Data is collected on the vehicle, the ambient environment, the highway environment and traffic conditions.

- Vehicle
  - Lighting system usage (no lights, running lights, low beams high beams)
  - Lighting system outage/misaim if observable
  - Vehicle speed
  - Direction of travel

- Ambient Environment
  - Ambient light
  - Weather conditions (rain/snow/fog, etc.)
  - Cloud coverage
  - Roadside features (snow, trees, etc.)
  - Time
- Highway Environment
  - Type of highway
  - Location of highway
  - Illumination of highway
  - Road surface type
  - Markings (lane and shoulder)
- Traffic Conditions
  - Average density of traffic (in the same direction and in opposing directions)
  - Time (and approximate distance) between preceding and succeeding vehicles.

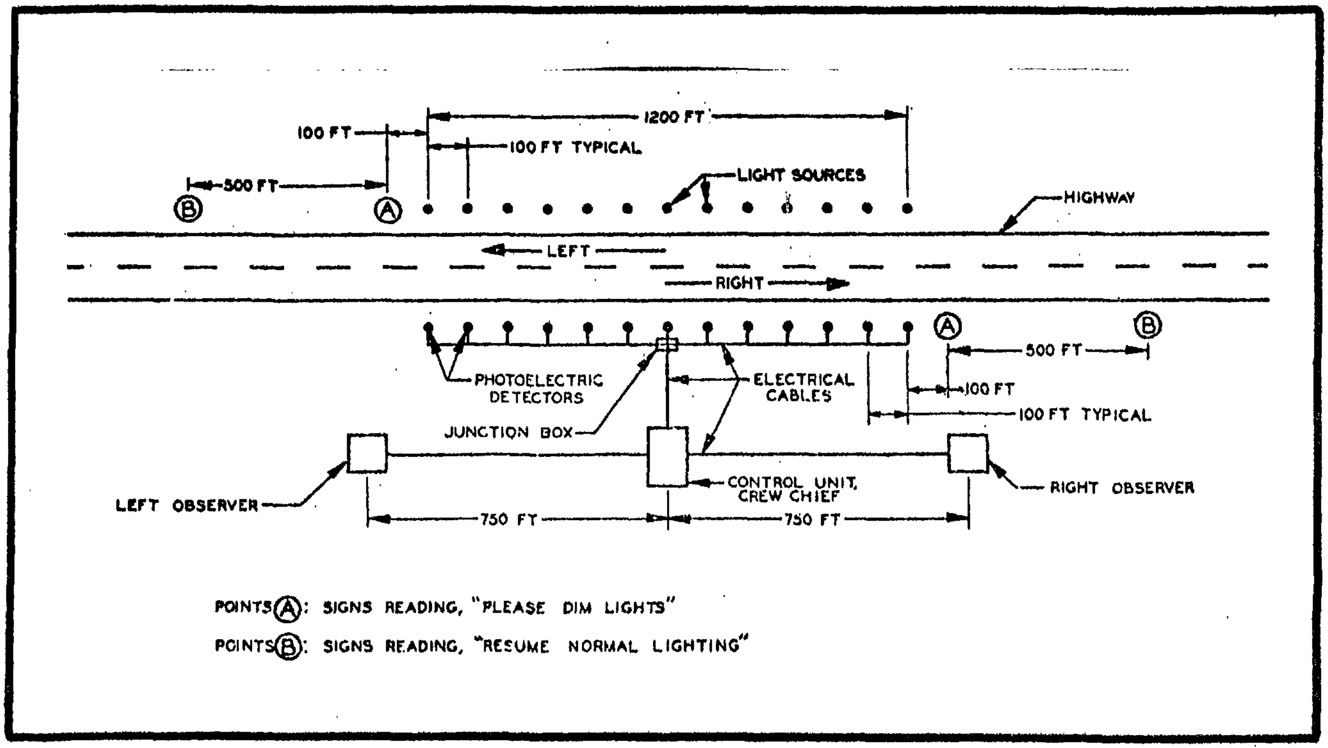
3.5.3 Data Acquisition and Preparation

The data acquisition and preparation has three basic steps: selection of areas for observation, raw data acquisition, and data reduction for the analysis. Since this study is meant to update the earlier Hemion and Hare study, the same classifications of areas should be used:

- Site Criteria
  - Two-lane, rural, unlighted sites
  - Four-lane, suburban, unlighted freeway
  - Two-lane, suburban, unlighted highway
  - Two-lane, suburban street with overhead lighting.
- Areas
  - Northeast
  - Mid-Atlantic
  - Southeast
  - Midwest
  - Gulf Coast
  - Rocky Mountains
  - Northwest
  - Southwest
- Topography
  - Mountainous
  - Rolling
  - Flat
- Climatic
  - Clear
  - Fog/haze
  - Rain
  - Snow.

Seventeen sites were sampled in the earlier study, each for four evenings, obtaining between 1,000 and 7,000 observations. In selecting sites for new roadside observations, consideration should be given to both the past sites and for locations where state highway departments have good records of hourly and seasonal vehicle counts. This later information is needed to project the rate of observed usage to total nighttime VMT.

The raw data acquistion should also follow the previous study. (See Figure 3-5 below.) In addition to that physical setup, it would be desirable to collect data on the ambient lighting conditions. In order to collect data on running light usage it will be necessary to run these observations from an earlier time, starting approximately 1 hour before sunset and continuing until several hours after sunset until there is total darkness.



Source: *Headlamp Beam Usage on U.S. Highways* [3].

Figure 3-5. Schematic diagram of test site.

3.5.4 Preliminary Results

Hare and Hemion give detailed results of the previous study: vehicle speeds, dimming actions given opposing vehicles, beam usage given traffic situations, traffic volume, weather, etc. [3]. No information on running light usage is known, nor has the lighting system usage been studied with regard to ambient lighting conditions.

3.5.5 Analysis

The analysis of the data will be in two parts. One will seek to update and compare with the earlier Hare and Hemion study to see if there have been significant differences in headlamp beam usage, for example, less high beam usage, more dimming earlier when two vehicles are meeting, etc. However, in general, the analysis will follow the earlier report. The second aspect will be lighting system usage in relationship with ambient lighting conditions. Presumably, the use of the lighting system will follow a progression from running lights to low beams to a mix of high and low beam usage as it becomes darker and traffic less dense. While running light (and thus side marker) usage should be sensitive to ambient lighting conditions, the mix of high and low beam usage might also be affected. The use of running lights may be very sensitive to regional differences, including state laws which require lights to be turned on at certain times. For instance, the State of California's Vehicle Code states,"No vehicle shall be driven at any time with the parking lamps lighted except when the lamps are being used as turn signal lamps or when the headlamps are also lighted" [8].

In conclusion, the analysis of lighting system usage should be related to ambient lighting conditions and those ambient lighting conditions should be related to times and locations for different seasons. This last information will be generated in the side collision analysis (Section 3.1).

3.6 Lighting System Outage

3.6.1 Introduction

The purpose of this study is to estimate how often vehicle lighting systems (headlamps and/or side marker lamps) are totally or partially failed.

This study is divided into two phases. The first phase will evaluate data from independent sources: state vehicle inspection data, NHTSA-sponsored defect identification programs and data collected in the headlamp misaiming study (Section 3.9) and lighting system usage study (Section 3.5). Depending on the results of the first phase, a second phase may be desired to clarify ambiguous results.

This study does not directly evaluate the effectiveness of the side marker lamps and high intensity headlamps in reducing accidents. This study is designed to investigate how often light components are failed and whether these failures are related to make/model lamp design, etc. Frequent outage reduces the potential effectiveness of the safety device, and, in the case of the headlamp being out, it can lead to an accident.

3.6.2 Data Requirements

This study has limited data requirements. Primarily, data are required on the vehicle, in particular:

- Make/Model/Model Year
- Headlamp type (2/4 beam, rectangular/round)
- Side Marker Lamp Design (separate/integral)
- Side Marker Lamp Outage (Left/right, front/rear).

3.6.3 Data Acquisition and Preparation

The minimum data will be from various state vehicle inspection programs, from previous NHTSA vehicle defect investigations, and from the misaiming of headlamp study (Section 4.9).* In obtaining data from the state vehicle inspection programs and the NHTSA vehicle defect investigations, one also needs to know the criteria for failure and other background information on the inspection program. That is, it may be important to know the frequency of inspection (annual, semiannual, etc.), the inspection agent (state, state-licensed), how recently the program was instituted, etc.

If the initial analysis of the data suggests consistent patterns of outage (aside from age-related) then further data collection would be desirable to establish whether some other factor has a significant relationship to outage, e.g.,

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*Twenty-nine states currently have periodic motor vehicle inspection programs. The Motor Vehicle Manufacturers Association has prepared a summary of state requirements on vehicle inspection [8].

certain types of vehicles (subcompacts) or certain makes of vehicles, or certain types of lamps (Type 2B) or some other factor, such as stringency of inspection program, etc. Any new inspection program should utilize existing state vehicle inspection programs. The existing state procedures would be refined, increasing level of detail on the particular factors where a significant influence is suspected. However, the structure and scope of any additional data collection is dependent on the results obtained from the analysis of existing, independent data sources.

3.6.4 Preliminary Results

Comparison of outage rates between different states reporting on similar components has shown significant differences [9]. The examination of vehicle defects also shows an increasing occurrence with age. In one specific NHTSA-sponsored program, backup lamps were found "out" in 15 percent of the cases. From inspection records in four states, low beam operation was faulty a significant amount of time (1 to 7 percent) and the range for side marker lamps was even higher (5 to 12 percent). Therefore outage of lighting components is not an infrequent event.

3.6.5 Analysis

The study will address the following questions:

- What is the level of outage of headlamps or side marker lamps in the vehicle-in-use population?
- Is the outage rate related in any consistent way to:
  - Age of vehicle
  - Headlamp or side marker lamp type
  - Area or inspection program
  - Vehicle market class
  - Vehicle make
  - Etc.?

The study will be conducted in two phases, the second phase being conditional upon the results of the first. The first phase will use existing, independent data from state inspection programs, NHTSA-sponsored defect investigations and the misaiming of headlamp study (Section 3.9).

The initial analysis of the above data will use these sources. If the results of the first phase are suggestive of relationships between outage and other factors, NHTSA may wish to collect additional vehicle defect data. That data should be obtained basically from existing state vehicle inspection programs. However, some additional kinds of data may be necessary then is currently collected by those programs. This could be the case if NHTSA-sponsored programs had results which were suggestive but not confirmable with state inspection program data because of lack of detail in the latter.

3.7 Sighting Distance Experiment

3.7.1 Introduction

The purpose of this approach is to collect data under controlled conditions that will allow an assessment of the effects of headlamp system, target type and glare on drivers' nighttime sighting distance.

Because this approach is a controlled experiment the results cannot be directly applied to real traffic situations. Nonetheless, the results of these trials will establish the effects of headlamp system and headlamp aim for different targets under moving vehicle conditions and will therefore more realistically reflect such effects than static absolute sighting distance tests could possibly provide.

A secondary aspect of the study will be to assess the effect of side marker lamps on the sightability of those vehicles.

3.7.2 Data Requirements

The most important design conditions are headlamp system (high intensity versus regular intensity), target characteristics and presence or absence of glare. It would be relatively straightforward to also include environmental conditions and various driver characteristics, however experimental costs in both time and personnel needed would grow very quickly.

For initial experimentation we are therefore considering only the three design variables of headlamp type, target type and glare type. For completeness we describe both the necessary variables and the possibly useful variables in more detail in the following list:

- Headlamp Factors
  - Type (high intensity vs. regular intensity)
  - Beam setting (high vs. low).
- Target Factors
  - Standardized reflectors: A flat surface one to two feet square with two given reflectance values (suggested values are 5% and 15%). The reflector will be positioned in a variety of locations including (i) in the roadway, (ii) on the two sides of the roadway and (iii) elevated on the sides of the roadway.
  - "Vehicle" target: It is impractical to use the variety of vehicles available as potential targets and it is unwise to pick just one vehicle as a target for the full experiment; therefore, we propose the use of a standard "vehicle" target device. Such a device will provide a "standard" vehicle profile when viewed from the side and will have a standard reflectance value (suggested 10%) and will also be designed to receive sidemarker lamps and headlamps for use in particular subexperiments.

- Glare Factors
  - Opposing glare: A frame which can be mounted with various headlamp configurations will be placed so as to create opposing glare. High intensity and regular headlamps with both high and low beams will be used. The headlamps will be placed in adjacent lanes, as on a two lane or four lane highway. Also, based on estimates of headlamp misaiming, in certain tests the lights will be misaimed. Glare intensity in foot-candles can be measured for different positions of the subject vehicle.
  - Following glare: This glare will be caused by a car following the subject vehicle and using various headlamp configurations in different trials (high intensity/regular, high/low beam, misaimed, etc.).
- Possible Environmental Factors
  - Wet vs. dry roadway
  - Road surface color/type (cement/asphalt)
  - Ambient light
  - Clear, rain, fog
- Possible Driver Factors
  - Visual acuity
  - Presence or absence of visual aids (glasses or contact lenses)
  - Age
  - Sex.

3.7.3 Data Acquisition and Preparation

The data will be collected under controlled field trial conditions. The experiments should be conducted at a test facility such as a large test track or abandoned airbase that affords a long straightaway (at least 1,500 feet), no undesirable light sources and is not demanding of driving skills when driven at a comfortable rate of speed (35-45 mph).

Experiments should be run in phases; initial results are to be used to establish the range of estimated effects and interactions so that later phases may be modified to take advantage of this new information. For example, initial indications of large differences in sighting distance for high intensity and regular intensity headlamp systems would allow for a reduction in the total number of trials needed to assert that there is a significant difference between high intensity and regular intensity systems.

For each of the experiments the test driver will be accompanied by a technician who will instruct and observe the driver. The driver will press a button on the steering wheel which will transmit a signal which indicates he sights the target so that the vehicle's position may be recorded. In addition, other technicians will record some aspects of the trial, for example, ambient light, road condition, environmental variables, etc.

The experiments and experimental data acquired from each can be organized as follows:

- Side marker Experiment
  - The "vehicle" target is placed on the right side of the track as if entering the course from the right in one of four "states": no lamps, sidemarker lamps only, headlamps (low beam) only, sidemarker and headlamps.
  - Since we wish to assess the effectiveness of sidemarker lights over light conditions of dusk to full darkness the ambient light must be recorded and each test driver would ideally be tested over the range of light conditions.
  - The test vehicle with test driver and technician aboard circles the track at some relatively constant speed and on each pass a "sighting" is made using high intensity or regular headlamps (low beam only but high beam could be incorporated).
  - The test subject, therefore, provides a set of sighting distances as below:

	Lights Headlamp	Target Vehicle			
		None	Side	Head	Side & Head
Test Vehicle	Regular				
	High Intensity				

Entry is "recorded sighting distance"

These data are provided for specific ambient light conditions.

  - Preliminary analyses should be made immediately to decide the number of test replications in the experimental conditions, since a great savings in time and money could be realized by an early stop to experimentation.

- High Intensity Versus Regular Headlamps
  - The goal is to determine what, if any, differences exist between these two headlamp system types in terms of test subjects' ability to sight reflector targets under three different conditions (no other light source situation, the oncoming vehicle situation, and the following vehicle situation). The reflector targets are of two types (5% reflectance and 15% reflectance) and will have one of four placements (elevated right side, right side, center of road, left side) in each trial. Furthermore, the oncoming and following vehicles will have various headlamp systems and beam levels. In particular we will consider high intensity and regular intensity systems using high beams, low beams and a "standard" misaimed beam.[*] Essentially, there are three logically similar subexperiments involved and each will now be discussed.

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[*] This could be provided by the headlamp misaiming study (Section 3.9).

- Lone vehicle subexperiment : On any given trial one of the two reflector targets is placed in one of the four possible positions. (A large track would allow for many trials to be completed in each circuit of the track.) The test vehicle with test subject and technician aboard circles the track and reports sighting using one of four headlamp conditions (high intensity/high beam, high intensity/low beam, regular/high beam, regular/low beam). The test subjects will therefore generate a table of sighting distances as below:

Intensity	Beam	Low Reflectance				High Reflectance			
		Position				Position			
		1	2	3	4	1	2	3	4
High	High	*							
	Low								
Regular	High								
	Low								

Preliminary analyses should be used to immediately decide the feasibility of an early stop to the testing procedure.

- Oncoming vehicle subexperiment: This is identical to the lone vehicle experiment except we use a headlamp system frame to simulate an oncoming vehicle using one of five lighting conditions (high intensity/high beam, high intensity/low beam, regular/high beam, regular/lowbeam, standard misaimed). The data generated from this experiment can therefore be thought of as five separate tables such as in the lone vehicle subexperiment - each table corresponding to a headlamp condition of the oncoming car.
- Following vehicle subexperiment: This is identical to the oncoming vehicle subexperiment but we are now using another vehicle to follow the test vehicle using one of the five headlamp lighting conditions and we are not using an oncoming vehicle headlamp system simultaneously. The data structure would be identical to that of the oncoming vehicle subexperiment.

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*The entries in this table will be sighting distance, i.e., distance between driver and target. This distance will be calculated by knowing the position of the vehicle and target when the sighting was reported by telemetry or recorded in the vehicle.

It is clear that the most efficient way to design the experiments would be to use a partially balanced design that precludes the estimation of higher order interactions but saves greatly on the number of subjects needed and especially on the number of conditions each subject must be tested under. The logic of such a design is simply that subjects are only tested under certain combinations of the experimental conditions rather than trying to have all subjects tested under all conditions. For planning purposes it would be convenient to have at least 32 subjects, but more subjects up to, say, 64 could be added in groups of 4 and the balanced nature of the design could be maintained.

3.7.4 Preliminary Results

Previous studies have been conducted to explore various characteristics and determinants of sighting distance. Of such studies one of the more complete is the HSRI study by Mortimer and Olson entitled *Development and Use of Driving Tests to Evaluate Headlamp Beams* [4]. Their report indicates we should expect definite main effects for headlamp beam, target placement and reflectance value in all the experiments. Furthermore, we should expect an interaction between target placement and beam usage in the oncoming vehicle situation irrespective of the oncoming vehicle's beam usage.

It is interesting to note that Mortimer and Olson did not use a partially balanced design; instead, they always had all subjects run under all conditions. However, they never used more than 15 subjects in such cases and their designs were not as large as those we suggest.

3.7.5 Analysis

Given the data structures as displayed in 3.7.3, the appropriate form of analysis is a straightforward application of analysis of variance. Certainly this will be the primary data analytic technique for each data set as described, but if variables such as ambient light, speed, road conditions, etc., are left "uncontrolled" they may be incorporated into the analysis through the auxiliary technique of analysis of covariance.

The sidemarker lamp data would be explored for effects using analysis of variance and the ambient light variable would be introduced as a covariate so that effectiveness for dusk to complete dark conditions could be summarized, since it has been suggested that the greatest effect occurs during the evening hours with little effect during night hours or during other periods of total darkness.

The headlamp system experiments are all designed for straightforward analysis by analysis of variance. Such analysis would provide not only assessment of significant effects, but would also provide actual estimates of the various effect's sizes.

Both experiments may be analyzed using the flow chart on the following page as the basic guide to the processes and logic of sequential analysis.

- Analysis of Side Marker Data
  - -The approach is essentially a 2x4 factorial analysis of variance. The final set of data will be analyzed as such, but we are recommending that as data are collected, various preliminary tests should be made to possibly simplify the experiment and reduce the time and effort of data collection.
  - -Early data analysis would allow for assessment of possible lack of differences in the target vehicles' "state," i.e., analysis could test for differences between "side marker lamps," "headlamps only," "side marker lamps and headlamps." If sighting differences did not differ dramatically between these states, then the experiment could be collapsed to a 2x2 analysis where target states are simply "no lamps" and "side marker lamps."
  - -Even if there is no desire to simplify the experimental structure, early analysis would allow for the creation of an error term that may immediately be used to determine the total number of observations need to "find" effects of any desired size. This would allow for the intelligent cessation of data collection rather than simply testing some predetermined number of subjects.

- <u>Analysis of High Intensity *vs.* Regular Headlamps Data</u>

  -There are three data sets to consider--one for each of the experiments: lone vehicle, oncoming vehicle, following vehicle.

  -Each of these data sets is amenable to factorial analysis of variance. The lone vehicle data is a 2x2x2x4 while the other two experiments yield a 2x2x2x4x5. Because of the size of the designs, it is important that analysis and experimentation proceed together. It would be very expensive to complete a full 2x2x2x4x5 experiment, although it may also be very informative.

  -Early data is used for two purposes just as in the sidemarker situation: (1) as a source of information that may be used to simplify the experimental design by collapsing certain categories of even variables, and (2) as a source of information for estimating the error variance which may be used to decide the total number of test subjects needed.

Finally, in the interpretation of the results of this experiment, there is the definite possibility that test drivers will "learn" as they proceed through the trials. The targets presented to the subjects are far from the unexpected type encountered in regular travel--these objects are not moving, they are not obscured, the surrounding area is homogeneous. Only in the case where the driver is blinded by glare will the target be much of a surprise. Therefore, the relative effects of high intensity versus regular intensity headlamps will be the most important information obtainable from this experiment.

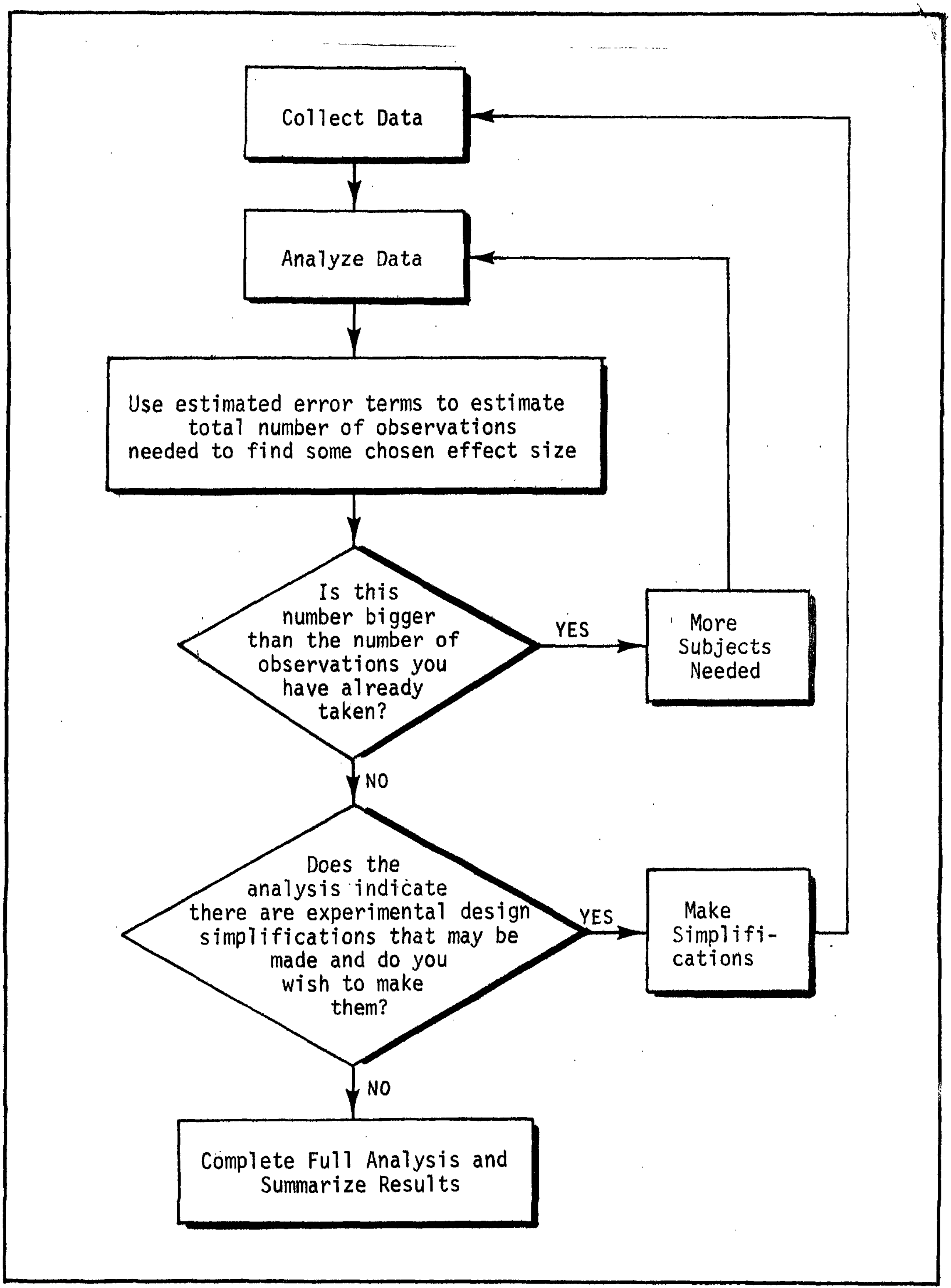

Figure 3-6. Analysis Flowchart for Headlamp System Experiments.

3.8 Adverse Weather Conditions

3.8.1 Introduction

The purpose of this study is to determine the relative performance of headlamps under adverse environmental conditions.

This study has relatively narrow focus and is concerned with the performance of headlamps in adverse, less typical circumstances. This study is important because of the problem of light scattering observed with the smaller regular intensity rectangular headlamps. There is more backscattering when there is rain or snow or fog and the light beam is scattered, rather than focused. This backscattering reduces the visibility of the driver.

If this study shows significant differences between headlamp designs, this information would affect the selection of accident situations where one would expect to find, through analysis, a real world effect of the Standard.

3.8.2 Data Requirements and Acquisition

This study has very limited data requirements. Basically for the different headlamp configurations* one would measure the degree of penetration and degree of backscatter given a standard set of environmental conditions (fog/rain/snow).** In addition to different types of headlamps, the relative position of headlamps to the driver/observer might also have an effect.

The data acquisition will require the use of a relatively large climate control chamber--large enough for a test frame with headlamps, and photometers 10 to 20 feet in front of and 5 to 8 ft behind the vehicle. The front wall needs to be non-reflective. The tests should be run as a full factorial design as only two measurements are required and the types of lamps are limited.

3.8.3 Preliminary Results and Analysis

The smaller regular intensity rectangular headlamps have a great number of small lenses built into the front lens to direct and focus the beam. It has been noted that this headlamp has considerable scattering of light and in conditions of rain or snow much of this light is picked up and reflected back toward the driver, reducing visibility [12]. The larger high intensity rectangular headlamps appear to have fewer small lenses and a smoother curved front surface. This should lead to less scattering. The results of the tests will establish this directly.

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*Two and four lamps, round and rectangular, regular and high intensity on high and low beam.

**It might also be desirable to run one set of these experiments with headlamps obscured with a coating of salt-/sand/mud spray typical of adverse weather driving conditions in many states. Such headlamp coatings often occur when there is snow, rain, or fog.

3.9 Misaiming of Headlamps

3.9.1 Introduction

The purpose of this approach is to examine the character and degree of misaiming of headlamps in the vehicle population.

The main thrust of this study is to determine if there are any consistent or adverse circumstances which lead to the misaiming of headlamps, first with regard to the new high intensity headlamps which are larger than the regular rectangular headlamps and second with regard to headlamps in general. Information about the degree of misaiming will be used with the results of other studies to infer the amount of unnecessary glaring taking place and the amount of reduced visibility this causes. Another potential use of the information depends on the nature of the results, but if the high intensity headlamps were consistently misaimed to the left or there was a higher degree of misadjustment between high and low beams, then the information may suggest the Standard is less effective then possible in reaching its objectives.

3.9.2 Data Requirements

For the analysis of headlamp misaim, information is required on two basic categories: the headlamps and the vehicle. The data readings on headlamp performance would include the position of the high intensity spot under various conditions, the maximum intensity and the intensity gradient. Other factors would be:

- Headlamp Factors
  - Headlamp type
    - 4 round headlamps
    - 2 round headlamps
    - 4 rectangular headlamps
    - 2 rectangular high intensity headlamps.
  - Headlamp outage* (high or low beam, left or right lamp).
  - Lamp replacement and aiming methods if known.
- Vehicle Factors
  - Make, model, model year
  - Height and separation of headlamps
  - Vehicle alignment/damage.

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*Outage of other lamps including side markers should also be done at this time.

- Vehicle loading
  - -- Driver only
  - -- Driver plus three men in back seat.

3.9.3 Data Acquisition and Preparation

The acquisition of the headlamp performance data requires the development of a testing facility and instrumentation. (1) Following the lead of earlier defect investigation programs the tests would be conducted at state vehicle inspection stations (possibly state licensed inspection stations), local diagnostic centers, or field "laboratories" set up locally. (2) The test facility would need a space where lighting could be relatively controlled, the vehicle could be accurately positioned on tracks, and an aiming screen could be placed about 25 feet in front of the headlamps. (3) Photometers will be needed to measure the intensity of the headlamp beam at different points. There are two potential methods of arranging the photometers: (a) to arrange many photometers in a grid pattern on the aiming screen and taking only one recording per instrument*, or (b) mounting one or more photometers on a track which runs in front of the headlamps and recording the intensity and position periodically. This latter method is recommended because of greater accuracy and flexibility. (4) When the test vehicle is brought in and positioned on the tracks a technician sits in the driver's seat, puts on the low beams, places the engine in neutral (or park) and runs the engine at about 2000 rpm because low idling speed may affect voltage to the lights. (5) The ambient light, the intensity of the low beams and the gradient of the light beams would be measured. At the same time other technicians could check for outage of other lights. The position of the high intensity spot could be derived from the intensity gradients. (6) Next the high beams would be tested. (7) The last test would be to load three technicians in the back seat of the vehicle to determine the vertical shift of the beam.

Prior to undergoing the testing procedure, vehicle owners would fill out a brief questionaire and release form. The questionaire would indicate make, model, model year and information on headlamp replacement and aiming.

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*If the aiming screen in 8 feet tall and 20 feet wide and the photometers concentrated primarily on these areas where the light intensity is assumed to be greatest (every 1 foot there), then the 50 or more photometers might be needed.

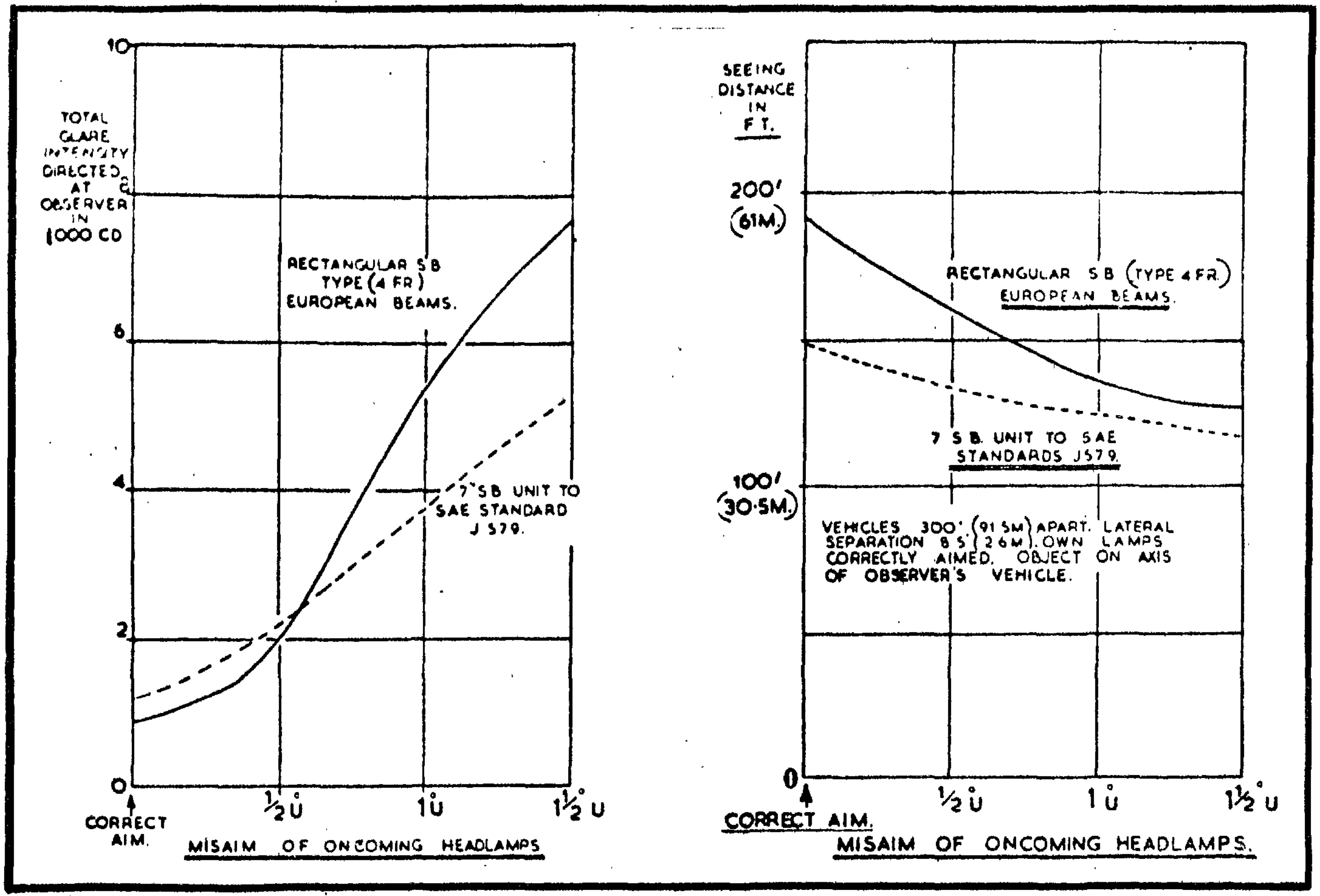
3.9.4 Preliminary Results

Misaiming of headlamps includes at least the following:

- Position of highest intensity is not correct.
- Misalignment between right and left headlamps.
- Inability to properly aim high and low beams in 2-lamp systems.
- Improper beam pattern due to filament (or lenses) defect.

Ultrasystems, in a study sponsored by NHTSA, found headlamps "misaimed" in 39 percent of the vehicles tested [10]. A California study found that when a 2-lamp system was visually aimed for low beam usage,in 58 percent of the cases the high beams were misaimed [13]. Also, this California study found large differences between vehicle makes and models and lamp type.

Jones and MacMillan show the effect of misaim, both the glare caused by misaimed headlamps and the reduction in sighting distance this causes. (See Figure 3-7 below.) This misaim can be caused either by the headlamps, the vehicle suspension and/or loading, poor installation or vehicle vibration.



Source: Jones and MacMillan [13].

Figure 3-7. Effects of misaimed headlamps.

3.9.5 Analysis

Some questions which can be addressed with a program which investigates headlamp aim are:

(1) Absolute rate of misaiming as measured by the position of the high intensity spot of individual lamps.

(2) Misaiming of headlamp groups, left vs. right.

(3) Incompatibility of high beam and low beam aiming, i.e., if one is properly aimed will the other be misaimed due to flaws in the headlamp construction.

(4) Do certain makes, models, model years, lamp types have consistent patterns of misaiming.

(5) Does a certain type of aiming procedure lead to greater misaiming.

(6) Is there an inverse relationship between state inspection and misaiming rate.

(7) How does the overall pattern of illumination compare given misaiming, flawed headlamps, makes, models, etc.

(8) What effect does vehicle loading, headlamp height and spread have on light pattern.

The data acquisition procedure is described in Section 3.9.3. The overall degree of "misaiming" is very high, about one-third; however, differences between makes, models, and model years will probably be much smaller. Therefore, the numbers of vehicles to be tested will be of the order of 5000 vehicles, according to the following breakdown.

- Make and model will be based on market class and market share--obviously the larger the market share the greater number of these vehicles would be desirable. This breakdown gives about thirty types of vehicle to be sampled. (See Table 3- 8 below.)

- Within each make/model combination, one would want to have the different types of headlamps:
  - Round, regular intensity, 2-lamp systems
  - Round, regular intensity,4-lamp systems
  - Rectangular, regular intensity, 4-lamp systems
  - Rectangular, high intensity, 2-lamp systems.

  However, within each vehicle type not all lamp types will be found.

- The model years of particular interest will be the latest model years 1976-1979, which will yield cars which are four years old at the time of the study, so that effects of age and replacement might be determined.

Therefore, if one were to test ten cars in each cell, assuming 30 car types, four lamp types, and four model years, one would need 4800 vehicles. This number is an approximation given that some market class/manufacturer combinations will not have all lamp types--particularly high intensity headlamps before 1978 models. On the other hand, given that differences between Chevrolet and Buick may be substantial, one might wish to subdivide the cell for General Motor Intermediates , etc.

TABLE 3-8

VEHICLE TYPE BY MANUFACTURER, 1974

Market Class	Manufacturer						
	GM	Ford	Chrysler	AMC	VW	Toyota	Datsun
Luxury	5.0	1.7	1.0	--	--	--	--
Medium	14.5	3.8	13.2	--	--	--	--
Full size	15.3	18.9	8.9	4.9	--	--	--
Intermediate	24.5	15.9	20.4	23.2	--	--	--
Compact	13.0	17.9	53.3	35.4	11.1	--	--
Subcompact	8.9	16.2	--	31.3	88.8	100.	81.6
Sports type	18.7	25.5	3.2	5.2	0.1	--	18.4
Overall share of market	41%	25%	13%	4%	4%	3%	3%

Source: Derived from *Wards 1975 Automotive Yearbook,* using their market class categories.

The analysis will be primarily an interpretation of the results of tests of the vehicles. The misaiming rates will be compared for different aged vehicles, for different make/market class vehicles, for different areas, for different types of headlamps, and for different aiming methods after replacement.

While the rates as collected stand alone, since each cell has few cases sampled, it is worthwhile to consider ways of increasing the accuracy of each rate estimate. The proposed method for doing this is to consider the rates as functions of headlamp type, vehicle age, etc. The rates then become dependent variables in a loglinear model (see Appendix B) with the other variables mentioned above as the independent variables. Those higher order interactions deemed insignificant indicate where collapsing is feasible, so that many different cells lend strength to the rate estimate in any one cell. Both the precision of the estimates, and their stability are increased.

The suggested sampling procedure and sample sizes are considered to be adequate for this type of study.

3.10 Conspicuity of Side Marker Lamps

3.10.1 Introduction

The purpose of this study is to determine if certain side marker lamp designs are more noticeable than other designs.

Because of small initial estimates of the effects of side marker lamps, the results of the analysis of side collisions may be inconclusive (Section 3.1). However, if the sighting distance experiment (Section 3.7) shows that side marker lamps are potentially beneficial during low light conditions, then it would be desirable to advocate the use of those designs which are most noticeable in hopes of increasing the beneficial effect of the side marker lamps. Gathering information on the noticeability of side marker lamps would be inefficient in the sighting distance experiment because of the large number of different types that could be shown. Secondly, any difference in effect may not be noticeable within the statistical analysis of side collisions. Therefore, a separate laboratory-controlled visual experiment is suggested to determine if different side markers are more noticeable.

This study will determine how noticeable a side marker lamp on a vehicle is by measuring how intense a slide projected image of the vehicle with marker lamp must be for a subject to identify the image.

3.10.2 Data Requirements

Data is required on four elements: driver (subject), vehicle (lamp design), ambient environment and recognition.

Specific elements are:

- Subject
  - Acuity
  - Glare Adaptability
  - Age and Sex
- Vehicle (to be identified)
  - Side Marker Lamp Design
    - integral/separate, front/rear
    - lamp intensity
    - size
    - reflectorizing
  - Vehicle size
  - Other light sources/reflectors visible from the side

- Ambient Environment (simulated by the test)
  - Glare intensity
  - Ambient light
- Recognition Measures
  - Intensity of vehicle image
  - Time to recognition at different intensity
  - Source of identification: side marker lamps or other light source

3.10.3 Data Acquisition and Preparation

In order to measure how noticeable different side marker lamp designs are one first will need pictures of the different designs on vehicles taken under identical circumstances. The vehicles should all be of the same color, and a neutral background--a dark color and dark background would be the worst circumstance. The lighting of the vehicle should be from the direction of the viewer as if illuminated by headlamps. The picture should be taken under darkened circumstance with headlamps on low beam (and side marker lamps lighted) from a position about 20 feet from the side of the car and in line with the front of the vehicle (since this is the more typical position for viewing). These pictures should be taken for the most popular models for each market class and manufacturer and side marker lamp type (basically integrated or separate lighting units). Also it is desirable to get pictures of special designs which might have more visibility.*

After a collection of slides are available, the test facilities need to be prepared. One will need a room with projection facilities and where the ambient light conditions can be controlled. There will be a standard glare source reducing the visual capability of the subject and simulating "worst" condition. The intensity of the image being projected must be controllable and accurate. This could be done by using a rheostat connected to the projector.

The test subjects will be relatively few in number (40 should suffice). They should be evenly divided between men and women and in two age groups, under 40 and 40 and over, since at this age visual abilities begin to deteriorate. This gives ten individuals in each group. One might also require that half of each group wear glasses to determine if glasses have a consistent effect.

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*Dirt and film may reduce the noticeability of side marker lamps considerably. The pictures should be taken of only clean, well-operating side marker lamps, however, in the analysis of results this problem of dirt should be addressed. For example, Mercedes has designed front and rear lamp components so that they do not become fouled.

The tests would be conducted as follows. Each subject would first be put in a darkened room for 10 - 15 minutes so that his or her eyes might become dark adjusted. The test would begin with the glare source light being turned on. With this light on, the subject would be asked to indicate when he noticed the image of a vehicle as it appeared on a screen in front of him. The intensity of the projected image would be gradually increased. The subject would press a button when he recognized the image and would speak into a microphone to indicate what led to recognition, e.g., side marker lamp or other light source. The pressed button would stop increasing the illumination of the image. Pressing that button, or perhaps some other, the illumination would be reduced and a new slide injected and the illumination being increased gradually again. The intensity of the projected image and the length of time to notice the image will be recorded. Each subject will view a relatively large set of pictures, though possibly not all possible make/model/lamp design combinations, during a test which lasts not more than one hour. If the test is much longer the subject's eyes may become too tired. During that test not all images will be of sighted vehicles--in some cases there should be unlit vehicles and other cases no vehicle at all. This should be done to reduce guessing on the part of the subject.

3.10.4 Preliminary Results and Analysis

This study is narrow in scope. It does not estimate the real world effectiveness of side marker lamps. It only estimates their relative noticeability. The value of this study is in the decision-making information it will provide. If no difference is found between lamp designs and no effect of side marker lamps is found in the side collision analysis, then the plan to phase out the side marker lamp requirements is reasonable. If certain designs appear more effective, however, NHTSA might require those designs be followed.

The evaluation of the results of the tests will be to group side marker lamp designs into categories according to intensity of image at which they were noticed and a group where vehicles were noticed due to light from other sources such as the headlamps or reflective surfaces. Those headlamp designs which were noted at the lowest image intensities would then be evaluated according to the size, shape, position, light intensity and color of the side marker lamps. One would look for commonalities between the best performers and dissimilarities with poorer performers. Light intensity will probably be one factor which is directly related to noticeability. Other factors might also have strong direct relationship. Therefore, the analysis may conclude that side marker lamps might improve noticeability in a variety of ways--intensity, possibly shape or position, etc.

Another factor to be considered in evaluating the noticeability of the side marker lamps is that they can become fouled with dirt and grime. Thus, a good performing side marker lamp (when clean) may be positioned in such a way or designed to catch dirt or snow. Mercedes is one manufacturer which has designed its forward and rear lighting components aerodynamically so that they are self-cleaning. Therefore, in evaluating the conspicuity of side marker lamps this element should be included.

For instance, a negative feature would be areas which receive dirt and spray from road travel, particularly low areas. Another negative feature would be deeply recessed markers which could catch dirt or snow. A good design would be a projecting lamp such that elements could not adhere and obscure.

3.11 Selective Repeal of Side Marker Lamp Requirements

3.11.1 Introduction

If the analysis of side collisions (Section 3.1) does not show any significant effect of side marker lamps, and other experiments like the sighting distance experiment (Section 3.7) and the conspicuity of side marker lamps (Section 3.10) provide inconclusive information on the potential effect of these lights, then it might be reasonable to selectively repeal side marker lamp requirements. As these requirements were eliminated the accident involvement of these vehicles would have to be monitored to guard against an inadvertent reduction in vehicle safety.

This test would not take place until after all other analyses of side marker lamps had taken place. The decision to go ahead with this type of test would require considerable cooperation with the vehicle manufacturers so that a balanced sample of vehicles were exempted from the Standard, e.g., a Buick intermediate but not a Chevrolet, etc. Even after agreement with the manufacturers, there is the manufacturing lead time and a period of data collection before any assessment of the effects of the repeal can be made. Another consideration in any selective repeal of side marker lamp requirements would be the liability both the manufacturer and the government would incur from those drivers whose vehicles do not have side marker lamps and are subsequently in side collisions.

In summary, it might be morally, practically and politically untenable to have a selective repeal of side marker lamp requirements for the purposes of testing for effectiveness. If all analyses of side marker lamps reveal no measurable effectiveness then the optimum strategy might be to make side marker lamps optional. In this case, the manufacturers would probably not phase out side marker lamps in a balanced, controlled fashion as would be statistically desirable. However, the mechanism for monitoring accident occurrance will exist with the National Accident Sampling System (NASS) and periodic evaluations of side collisions would then be reasonable for it would be monitoring for degradation in safety.

The analysis would be exactly the same as recommended in Section 3.1--Analysis of Side Collisions. The analysis would use data collected by NASS and thus could investigate accident severity as well as accident occurrence.

3.11.2 Data Requirements

The basic data requirements are the same as in Section 3.1.2 for the Analysis of Side Collisions on drivers, vehicles, ambient conditions, highway characteristics and traffic characteristics. Additional data will be available from NASS on the severity of the accident in terms of occupant injuries and vehicle damage.

3.11.3 Data Acquisition and Preliminary Results

The data acquisition and preparation would be performed by NASS data collection teams. They will sample approximately 15,000 motor vehicle accidents per year in at least 35 sites. The rate of data acquisition will be slow because even the maximum number of vehicles that one could expect to be changed to no side marker lamps would be less than 5 percent of the vehicle population per year.* Given the low rate of change and small effect of side marker lamps, the monitoring of side collision accidents may take several years before any conclusions can be reached.

3.11.4 Analysis

The analysis of the effects of repealing side marker lamp requirements will follow the analysis of side collisions discussed in detail in Section 3.1. In addition to that analysis some refinements are possible because of the greater detail of the NASS data. Although the side marker lamps are designed for accident prevention or avoidance, it may be that they reduce the severity of accidents. Therefore using the accident severity measures--vehicle damage, or possibly driver injury--an analysis could focus on differences in severity of side collision between vehicles with and without side marker lamps controlling for speeds and weights of the involved vehicles and other physical factors.

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*One would desire a maximum of one-half the vehicles in any model year to change and a more likely amount one could expect is one-quarter of new cars to change. Given 120 million vehicles in the population and 10 million vehicles produced per year, less than 5 percent of the vehicle population could be expected to have dropped side marker lamps per year.

3.12 Selective Introduction of High Intensity Headlamps

3.12.1 Introduction

If the analyses of hazardous locations (Section 3.4), overdriving headlamps (3.2), glare complaints (3.3), and the sighting distance experiment (3.7) reveal no consistent effect attributable to high intensity headlamps, it would be reasonable for NHTSA to arrange a selective test of high intensity headlamps. This test would be such that for selected make/model combinations, one-half would be produced with regular high intensity headlamps while the other vehicles of the same make/model would have the same headlamps however the filament would be smaller reducing the candlepower to that of regular intensity headlamps. In this case one would have a Type A and Type B for selected make/models, e.g., Chevrolet Impala, and given a large enough sample the analysis could simply focus on the different nighttime accident rates of the A's and B's.

NHTSA would face a considerable quandary in requiring this equipping of vehicles. However, since the higher intensity headlamps are desired by the manufacturers, the proof of safety might be placed on them. In this case NHTSA would like to examine the evidence of a controlled experiment such as that described above. This position would be most tenable if the effect of high intensity headlamps is not clear from the other analyses suggested and secondly if the cost of these headlamps remains so much higher than regular headlamps.*

3.12.2 Data Requirements, Acquisition and Preparation

Given that a significantly large group of vehicles were equipped with one of the two headlamp intensities each year, then the comparison of nighttime accident rates can be directly compared, at least initially. The data will be collected by NASS. The basic information which will be necessary will be accident type, location and time.

3.12.2 Preliminary Results and Analysis

The major criterion of such a study is the random distribution of a significant number of vehicles differing only in one respect--headlamp intensity. The examination of nighttime accidents will focus on whether vehicles with high intensity headlamps are in fewer nighttime accidents. Additionally the types of nighttime accidents will be examined to determine if the high intensity headlamps are more effective in certain situations but not in others.

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*In the event that glare significantly increases accidents, NHTSA might have to restrict use of high intensity headlamps. A controlled experiment would then become even more untenable.

Also the distribution of driver characteristics will be examined to determine if high intensity headlamps are more effective for certain drivers and not for others.

In general, the analysis will be similar to the overdriving headlamp experiment (Section 3.2). However, the analysis of the accident data will be much simpler because the vehicles with and without high intensity headlamps will be identical in all other respects--presumably including the mix of drivers and accident exposure.

3.13 References for Section 3

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4.0 COST DATA AND SAMPLING PLAN

4.1 Background

Side Marker Lamps

The current version of FMVSS 108 as it pertains to side marker lamps for passenger cars became effective January 1, 1970. It requires all passenger cars manufactured after this date to be equipped with side marker lamps in order to improve the ability of drivers to locate and estimate distances between vehicles at angles during darkness and other conditions of reduced visibility.

Compliance with the Standard on vehicles manufactured after January 1, 1970 requires side marker lamps to be permanently mounted on rigid parts of the vehicle not less than 15 inches above the road surface. The photometric minimum candlepower requirement for each side marker lamp is now specified by SAE J592e (effective May 29, 1974). Their activation must be linked to the activation of the parking lamps and vehicle headlamps in the steady beam state. Some models satisfy the Standard by enlarging the front (and/or rear) lighting group to be visible from the side. Other vehicles use a wholly separate side marker lamp.

NHTSA was not required to obtain cost data when the side marker requirements became effective. The costs of compliance are probably small, but no cost data is available [1].

High Intensity Headlamps

The current version of FMVSS 108 as it pertains to headlamps on passenger vehicles became effective January 1, 1969. Rectangular headlamps were allowed after January 1, 1974, but they still had to meet the performance standards established in 1969. The latest version of the Standard doesn't require high intensity Type 2B headlamps on vehicles manufactured after November 1, 1976. These headlamps exhibit about 20 percent higher output in low beam performance and up to 100 percent improvement in high beam performance.

Obviously, vehicles in use before January 1, 1969 were already equipped with headlamps. The purpose of FMVSS 108 was to establish requirements for original and replacement headlamps. There are currently five basic headlamps being used to comply with the Standard:

(1) Type 1 - Round sealed beam headlamps with one filament used for high beam.

(2) Type 2 - Round sealed beam headlamps with two filaments used primarily for low beam and secondary high beam.

(3) Type 1A - Rectangular sealed beam headlamps with one filament used for high beam.

(4) Type 2A - Rectangular sealed beam headlamps with two filaments used primarily for low beam and secondary high beam.

(5) Type 2B - Rectangular sealed beam high intensity headlamp similar to Type 2A with improved photometrics.

Passenger cars might satisfy the Standard by using these lamps in one of four systems:

(1) Using 2 white (7 inch in diameter) Type 2 headlamps in a 2-lamp system.

(2) Using 2 white (5-3/4 inch in diameter) Type 1 headlamps and 2 white (5-3/4 inch in diameter) Type 2 headlamps in a 4-lamp system.

(3) Using 2 Type 1A headlamps (100 mm x 165 mm) and 2 Type 2A headlamps (100 mm x 165 mm) in a 4-lamp system.

(4) Using 2 Type 2B headlamps (142 mm x 200 mm) in a 2-lamp system.

The rectangular high intensity headlamps (Type 2B) must comply with SAE J1132. The proposed maximum output for these lamps is 150,000 candela (75,000 apiece). These headlamps must be positioned on the front of the vehicle between 24 and 54 inches above the road surface, one on each side of the vehicle centerline as far apart as practicable.

Estimates of the average costs involved in providing high intensity lighting through the use of various headlamp systems are available through the NHTSA headlamp specialist. These average costs are as follows:

Type 2B Headlamp System:

- Cost of conventional Type 2 (70inch diameter) lamp ranges from $1.00 to $2.50 per lamp [2]. The GM dealer price is from $4.14 to $5.11 forthe round lamps [3].
- Estimated cost of Type 2B (High Intensity Lamp) ranges from $3.00 to $7.50 per lamp, based on mass production [2].

If one were to achieve the increased illumination by altering the existing Type 2 (7-inch diameter) headlamp with a heavier filament, it would cost about $0.01 per lamp. Using a quartz halogen light source would cost from $3.00 to $4.00 per lamp.

4.2 Relevant Cost Items

Side Marker Lamps

The major components of a side marker lamp system are shown in Table 4-1. The addition of any of these components to existing side marker systems as a result of FMVSS 108 should be included in the cost of compliance.

TABLE 4-1

MAJOR COMPONENTS OF SIDEMARKER LAMP SYSTEM

(1) 2 amber reflector lamp shields
(2) 2 red reflector lamp shields
(3) 4 lamp bulbs
(4) Circuit fuses
(5) Wiring.

High Intensity Headlamps

The major components of a high intensity (Type 2B) head lamp system are shown in Table 4-2. It should be made clear that NHTSA does not require the use of high intensity lighting nor does it necessarily support the use of Type 2B headlamps for increased illumination; the Type 2B was desired by the manufacturers [2]. The 150,000 candela now allowed could be attained through the use of heavier filaments and stepped-up voltage in existing Type 2 (7 inch in diameter) headlamps, or through the use of quartz halogen lamps.

TABLE 4-2

MAJOR COMPONENTS OF HIGH INTENSITY HEADLAMP SYSTEMS

(1) 2 sealed beam high intensity lamp units (Type 2B)
(2) Voltage regulator
(3) Associated wiring.

To establish total costs, other items must be included in addition to the material costs of components. At the very least, direct and indirect manufacturing costs and capital investment must be considered. Consumers certainly pay for the marginal effect of manufacturers' markup, dealers' markup, and taxes when they purchase the vehicle. The NHTSA methodology also includes lifetime operating and maintenance costs as part of the total cost of a design change. We will not include these lifetime costs.

The manufacturing costs are a function of:

- Material amount
- Material costs
- Labor required for component assembly
- Wage rate
- Overhead rate (indirect labor and materials)
- Labor required for component installation.

Capital investment should be amortized over the useful life of the equipment and estimated level of production. Manufacturers' markups, dealers' markups, and taxes are estimated percentage amounts applied to the base costs.

4.3 Plan for Acquisition of Cost Data

The purpose of this activity is to acquire reliable estimates of the incremental costs incurred by manufacturers in complying with FMVSS 108.

The cost of side marker lamps and high intensity headlamps can be determined from information supplied by the manufacturer. When this information is acquired on various models for years both before and after the Standard was effective, the incremental cost of compliance can be ascertained by extrapolation. Acquiring the necessary information for all models produced, in all relevant variations, is costly and unnecessary. If we assume some structure for the cost of compliance, it is then possible to design a sampling scheme whereby only some automobile models are examined. The particular structure assumed for the cost will lead to the sampling plan, and the stronger the assumptions, the smaller the sample size needed. For example, if it is assumed that costs are the same for all models and manufacturers, only one observation need be made. Side marker lamp costs will vary according to the manufacturer and market class. For high intensity headlamps, the major cost will be the lamps themselves, but the cost of associated components and redesign may well vary according to the manufacturer and market class.

Assuming that the cost of compliance is the sum of two components, one depending only on the manufacturer and the other only on the market class of the vehicle, these components can be estimated and the assumption of additivity checked. By careful choice of models for which cost information is collected, it is possible to limit the errors in the estimated cost of compliance that will result from over-simplifications in the assumed structure of the cost.

For the purposes of discussion, it is assumed that cost data will be collected on a limited number of models--say between 15 and 25. Manufacturers are considered according to their impact on the market, i.e., total volume of sales of various model classes are considered by sales volume for each major manufacturer. Approximate data for 1974 new automobiles are given in Table 4-1.

Using the seven manufacturers and seven market classes listed in Table 4-1, let the cost of compliance be c_{ij} for manufacturer i and market class j: that is, GM = 1, Ford = 2,...Datsun = 7, for i and Luxury = 1, Medium = 2,..., Sports type = 7 for market class. From Table 4-1, certain combinations are not present, limiting the sampling to be done. Toyotas come only in subcompacts, for example.

Assuming an additive model, the cost of compliance can be written:

$$c_{ij} = \alpha_i + \beta_j$$

where α_i is the component of cost for manufacturer i and β_j is the component of cost for market class j. Once these components are estimated, cost estimates for all automobiles produced are immediately available. To eliminate the redundancy between the α's and β's, a constraint must be imposed. A common one is that the sum of the α's (or β's) be zero.

TABLE 4-1
VEHICLE TYPE BY MANUFACTURER, 1974
(percent)

Market Class	Manufacturer						
	GM	Ford	Chrysler	AMC	VW	Toyota	Datsun
Luxury	5.0	1.7	1.0	--	--	--	--
Medium	14.5	3.8	13.2	--	--	--	--
Full size	15.3	18.9	8.9	4.9	--	--	--
Intermediate	24.5	15.9	20.4	23.2	--	--	--
Compact	13.0	17.9	53.3	35.4	11.1	--	--
Subcompact	8.9	16.2	--	31.3	88.8	100.	81.6
Sports type	18.7	25.5	3.2	5.2	0.1	--	18.4
Overall share of market	41%	25%	13%	4%	4%	3%	3%

Source: Derived from *Wards 1975 Automotive Yearbook*, using their market class categories.

At least thirteen automobile models need to be sampled: for example, one from every market class for GM, and then one from each of the other six manufacturers. Costs for all permissible combinations follow directly from the assumed cost structure. It is also clear that unless more models are sampled, these assumptions cannot be checked, so that while the costs for GM (41 percent of the market) are known, cost estimates for the other manufacturers may be way off. When it is possible to gather more data by suitable sampling, much additional information can be acquired, enabling checking of assumptions and nearly uniformly optimal precision in the estimates of cost. The theory of experimental design, a highly specialized branch of regression and analysis of variance (see the statistical Appendix B), guides the selection of models, but since the overall cost of compliance with the Standard is to be estimated, the relative contribution of each manufacturer/market class combination must also be taken into account.

The following is one good scheme that is also economical. From each of the classes listed, collect cost information on one model, which is taken as representative of the entire class.

GM: Luxury, Medium, Intermediate, Sports type
Ford: Full size, Compact, Subcompact, Sports type
Chrysler: Medium, Compact
AMC: Intermediate, Subcompact
VW: Subcompact
Toyota: Subcompact
Datsun: Subcompact

With cost information on these fifteen classes, all the α and β parameters can be estimated. If the assumed structure for the cost is correct, various contrasts (such as GM Medium - GM Sports type + Ford Sports type - Ford Compact + Chrysler Compact - Chryeler Medium) should be zero, within the error from the sampling. This can be tested.

If more observations can be taken, either more classes can be selected (GM Full size, Ford Intermediate,...) or more than one model can be chosen in a class, or both of these can be done. Selection of more than one model in a class (say in the GM Intermediate class Chevelle and Cutlass) gives an estimate of cost variability within a class.

The plan described above is suitable for side marker lamps.

Since not all models will have, and perhaps not all manufacturers will offer, models with high intensity headlamps, a different sampling plan to determine the incremental cost of the high intensity headlamps may be necessary. Initially, we suggest that costs be collected on one model with the high intensity headlamps from each major American manufacturer. If these costs differ much from one another, then more detailed investigation may be worthwhile.

4.4 References for Section 4

1. Personal communication with NHTSA FMVSS 108 (Rearlighting and Other Lights) Specialist, September 29, 1977.
2. Personal communication with NHTSA FMVSS 108 (Headlighting) Specialist, September 26, 1977.
3. _____. "New Car Lights are a Waste of Money," *The Star*, September 20, 1977.

5.0 WORK PLAN

The Work Plan for the evaluation study of FMVSS 108 is divided into nine Tasks. They are:

- Task 1: Analysis of Mass Accident Data: Side Collisions
- Task 2: Laboratory Tests of Adverse Weather Effects on Glare (Headlamps)
- Task 3: Sighting Distance Field Test (Side Marker Lamps & Headlamps)
- Task 4: Laboratory Test of Conspicuity of Side Marker Lamps
- Task 5: Field Data Collection at Hazardous Locations (Headlamps)
- Task 6: Analysis of Mass Accident Data: Overdriving and Glare
- Task 7: Survey of Lighting System Usage (Side Marker Lamps and Headlamps)
- Task 8: Misaiming of Headlamps & Light Outage Rates
- Task 9: Cost Data Analysis.

The logical sequence of subtasks within each Task is given in Figure 5-1. The time sequencing within each Task and the estimated resources required are given in Figure 5-2 and Figure 5-3. For the purpose of developing this Work Plan, the entire study is assumed to start on January 1, 1979.

Four Tasks are scheduled to be completed during the first two years of the evaluation study. The two Tasks to be completed during the first year include an analysis of the effects of side marker lamps on side collisions using mass accident data (Task 1) and laboratory tests of the effects of adverse weather conditions on glare for evaluating high intensity headlamps (Task 2). A third Task dealing with sighting distances under field test conditions will apply to both aspects of the Standard and be completed in the first half of the second year. The laboratory test of the conspicuity of side marker lamps is completed near the end of the second year. Two Decision Points relative to side marker lamps occur at the end of the first and second years. A single Decision Point relative to high intensity headlamps takes place in the first half of the second year.

The remaining four evaluation Tasks are conducted during the final two years of the study. Only a single Decision Point is scheduled in the time prior to the final Decision Points for both aspects of the Standard which occurs 50 months after beginning the study. This Decision Point concerns headlamps and is planned at Month 32 following the completion of the field data collection at hazardous locations (Task 5) and the first part of the analysis of the effects of overdriving and glare from mass accident data (Task 6). Work during the fourth year is

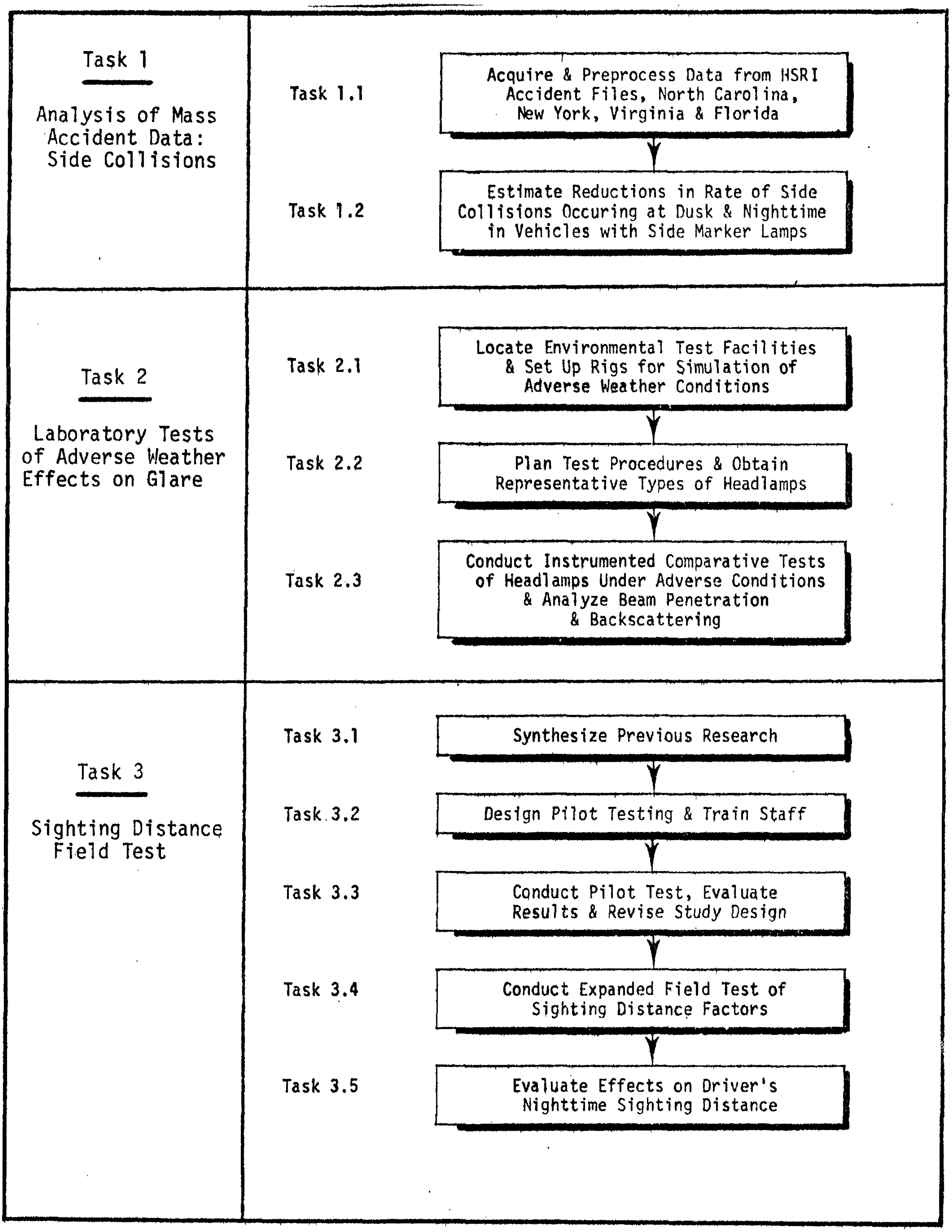


Figure 5-1. Flow chart for proposed study to evaluate FMVSS 108: Side Marker Lamps and High Intensity Head Lamps.

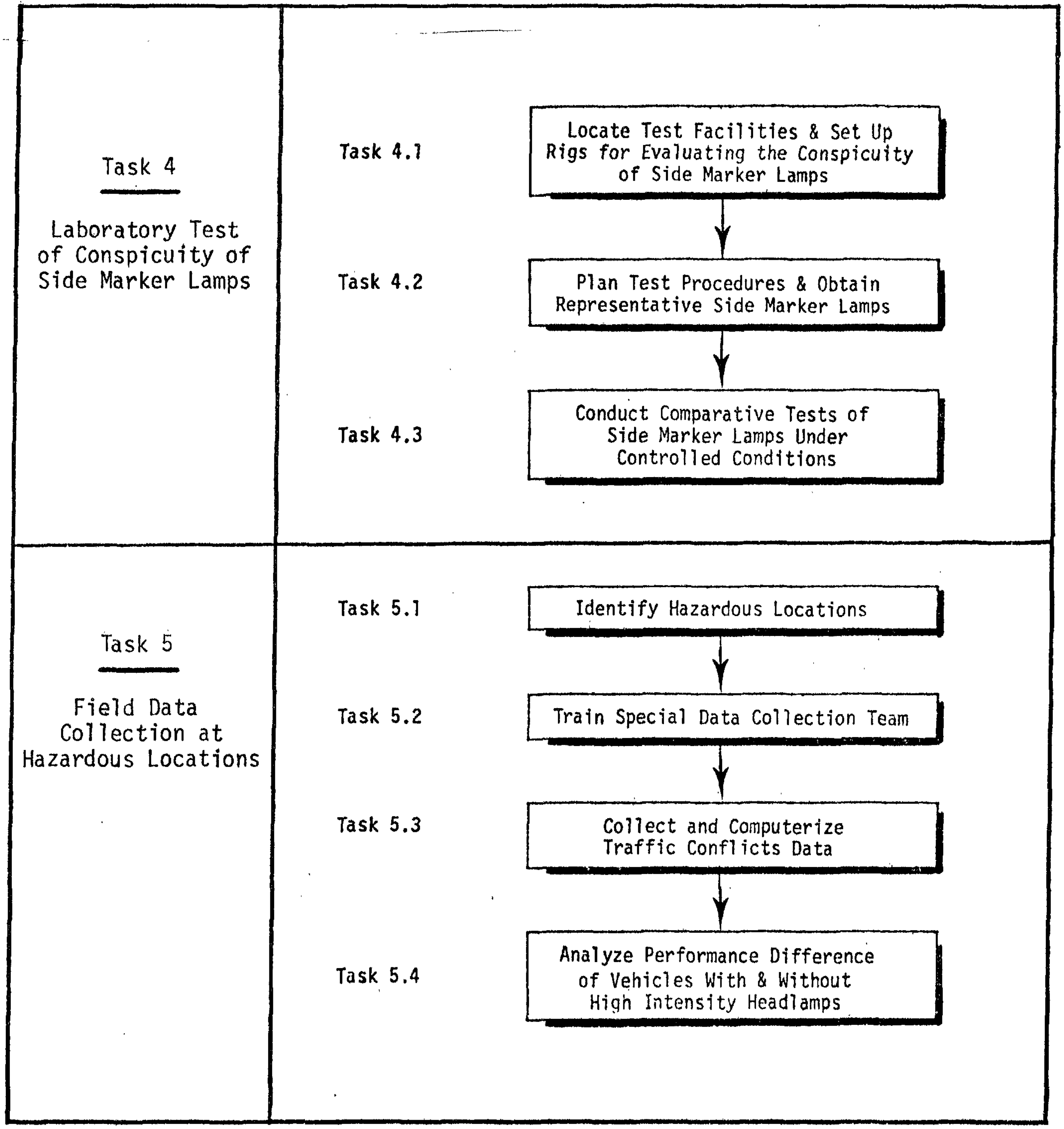


Figure 5-1 (continued).

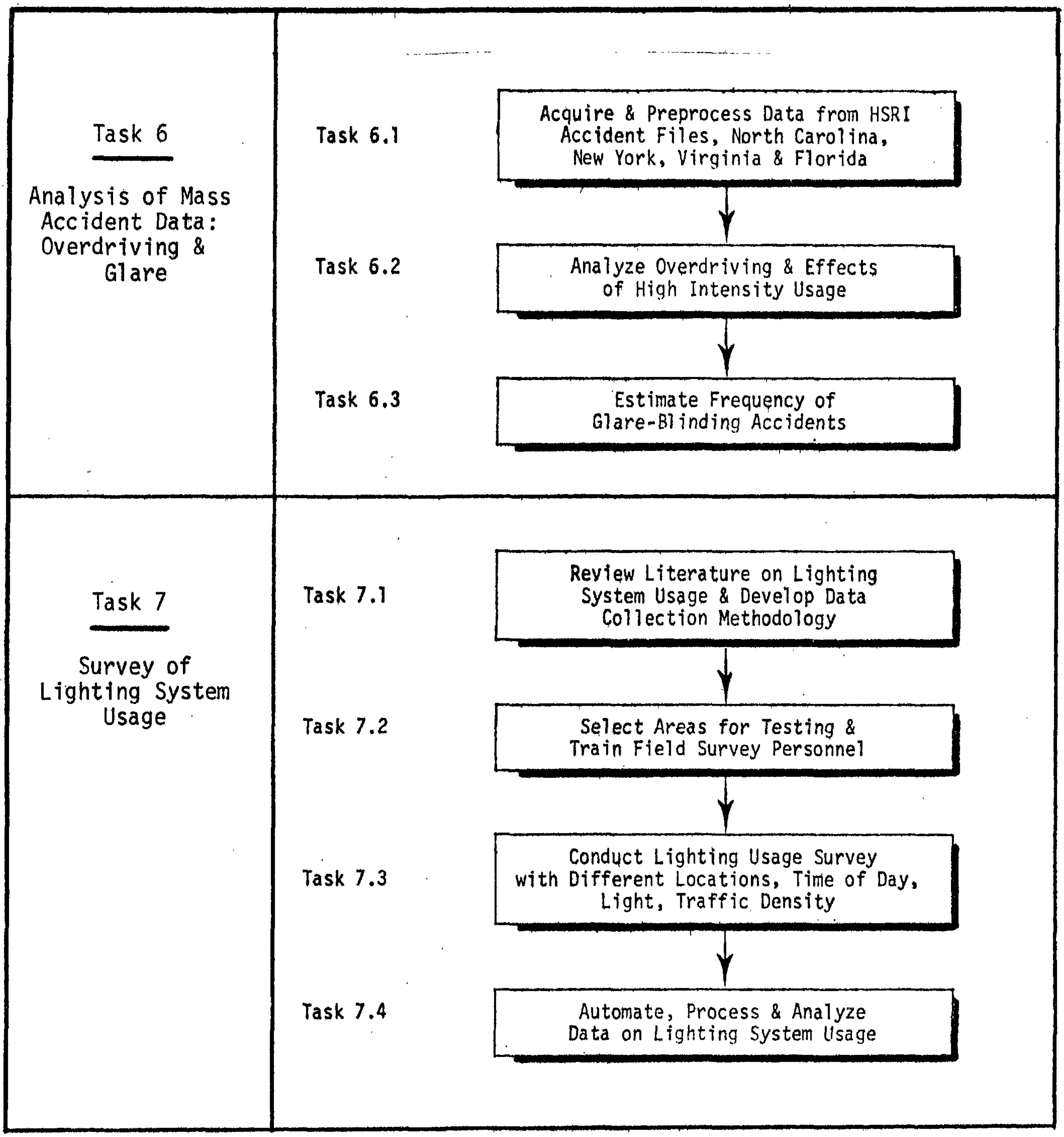


Figure 5-1 (Continued).

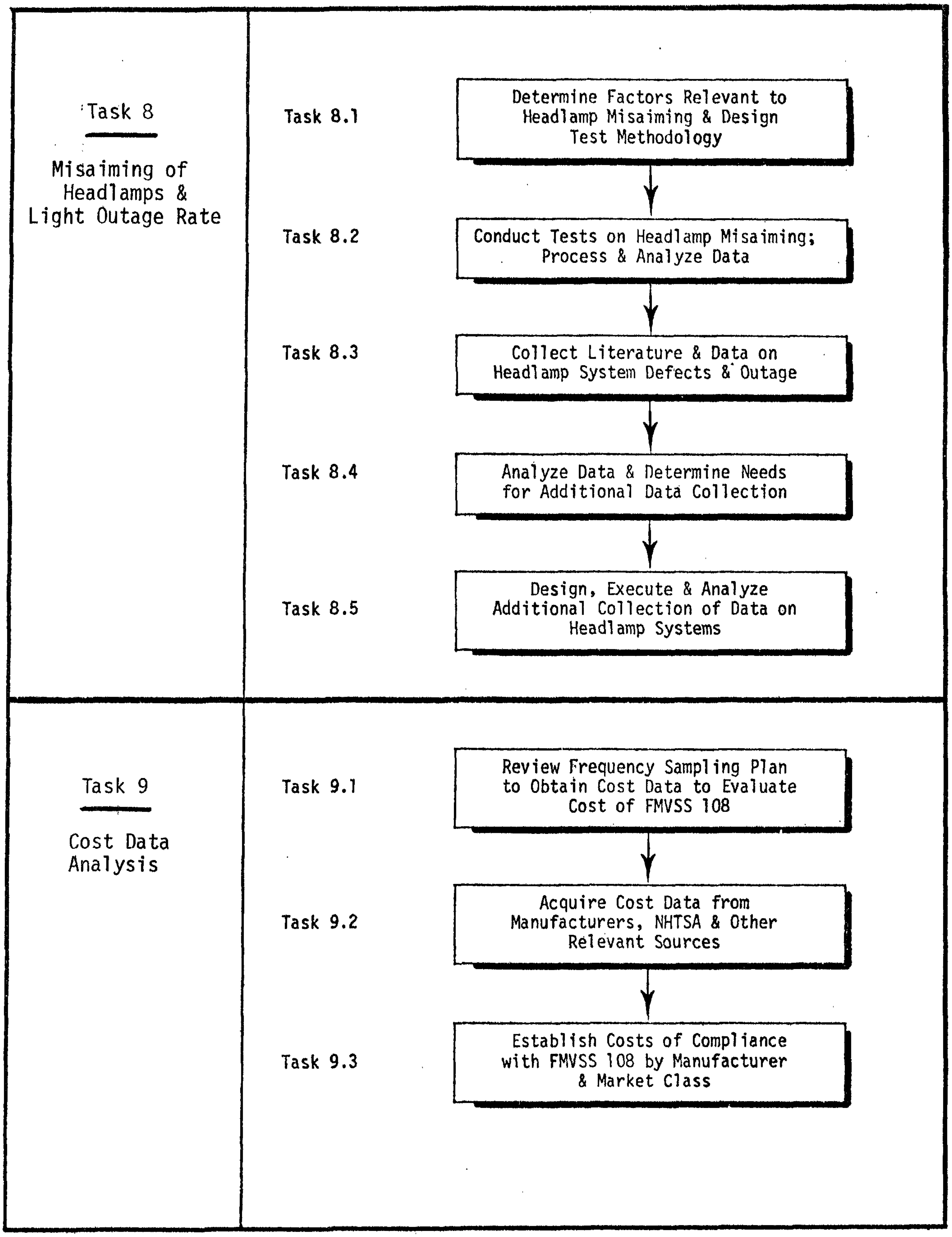
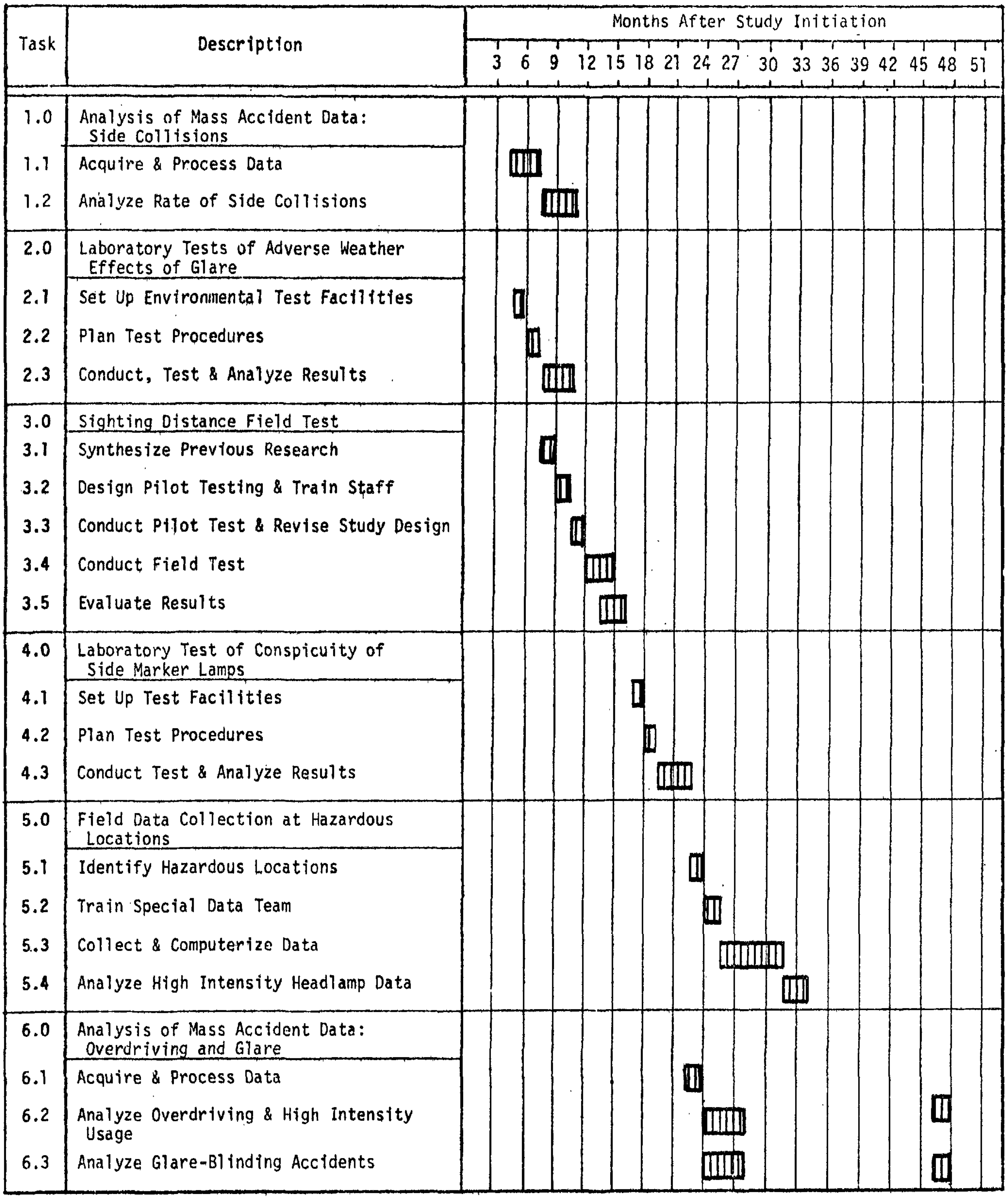


Figure 5-1 (Concluded).



Task	Description
1.0	Analysis of Mass Accident Data: Side Collisions
1.1	Acquire & Process Data
1.2	Analyze Rate of Side Collisions
2.0	Laboratory Tests of Adverse Weather Effects of Glare
2.1	Set Up Environmental Test Facilities
2.2	Plan Test Procedures
2.3	Conduct, Test & Analyze Results
3.0	Sighting Distance Field Test
3.1	Synthesize Previous Research
3.2	Design Pilot Testing & Train Staff
3.3	Conduct Pilot Test & Revise Study Design
3.4	Conduct Field Test
3.5	Evaluate Results
4.0	Laboratory Test of Conspicuity of Side Marker Lamps
4.1	Set Up Test Facilities
4.2	Plan Test Procedures
4.3	Conduct Test & Analyze Results
5.0	Field Data Collection at Hazardous Locations
5.1	Identify Hazardous Locations
5.2	Train Special Data Team
5.3	Collect & Computerize Data
5.4	Analyze High Intensity Headlamp Data
6.0	Analysis of Mass Accident Data: Overdriving and Glare
6.1	Acquire & Process Data
6.2	Analyze Overdriving & High Intensity Usage
6.3	Analyze Glare-Blinding Accidents

Figure 5-2. Schedule of tasks for evaluation of FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only).

Task	Description	Staff Years	Staff Cost ($)	Data Processing Cost ($)	Lab Cost ($)	Equip-ment Cost ($)	Field Data Cost ($)	Total Cost ($)
1.0	Analysis of Mass Accident Data: Side Collisions							
1.1	Acquire & Process Data	0.2	10K	2K	-	-	-	12K
1.2	Analyze Rate of Side Collisions	0.3	15K	2K	-	-	-	17K
	Total	0.5	25K	4K	-	-	-	29K
2.0	Laboratory Tests of Adverse Weather Effects of Glare							
2.1	Set Up Environmental Test Facilities	0.2	10K	-	0.5K	1.5K	-	12K
2.2	Plan Test Procedures	0.2	10K	-	-	-	-	10K
2.3	Conduct, Test & Analyze Results	0.4	20K	-	4K	-	-	24K
	Total	0.8	40K	-	4.5K	1.5K	-	46K
3.0	Sighting Distance Field Test							
3.1	Synthesize Previous Research	0.1	5K	-	-	-	-	5K
3.2	Design Pilot Testing & Train Staff	0.2	10K	-	-	-	-	10K
3.3	Conduct Pilot Test & Revise Study Design	0.4	20K	-	1K	1K	-	22K
3.4	Conduct Field Test	0.9	45K	-	4K	4K	-	53K
3.5	Evaluate Results	0.4	20K	2K	-	-	-	22K
	Total	2.0	100K	2K	5K	5K	-	112K
4.0	Laboratory Test of Conspicuity of Side Marker Lamps							
4.1	Set Up Test Facilities	0.2	10K	-	0.5K	1.5K	-	12K
4.2	Plan Test Procedures	0.2	10K	-	-	-	-	10K
4.3	Conduct Test & Analyze Results	0.4	20K	-	4K	-	-	24K
	Total	0.8	40K	-	4.5K	1.5K	-	46K
5.0	Field Data Collection at Hazardous Locations							
5.1	Identify Hazardous Locations	0.1	5K	-	-	-	-	5K
5.2	Train Special Data Team	0.2	10K	-	-	-	-	10K
5.3	Collect & Computerize Data	0.2	8K	1K	-	-	30K	39K
5.4	Analyze High Intensity Headlamp Data	0.3	15K	1K	-	-	-	16K
	Total	0.8	38K	2K	-	-	30K	70K
6.0	Analysis of Mass Accident Data: Overdriving and Glare							
6.1	Acquire & Process Data	0.2	10K	2K	-	-	-	12K
6.2	Analyze Overdriving & High Intensity Usage	0.4	20K	2K	-	-	-	22K
6.3	Analyze Glare-Blinding Accidents	0.3	15K	2K	-	-	-	17K
	Total	0.9	45K	6K	-	-	-	51K

Figure 5-3. Schedule of required resources for evaluation of FMVSS 108.

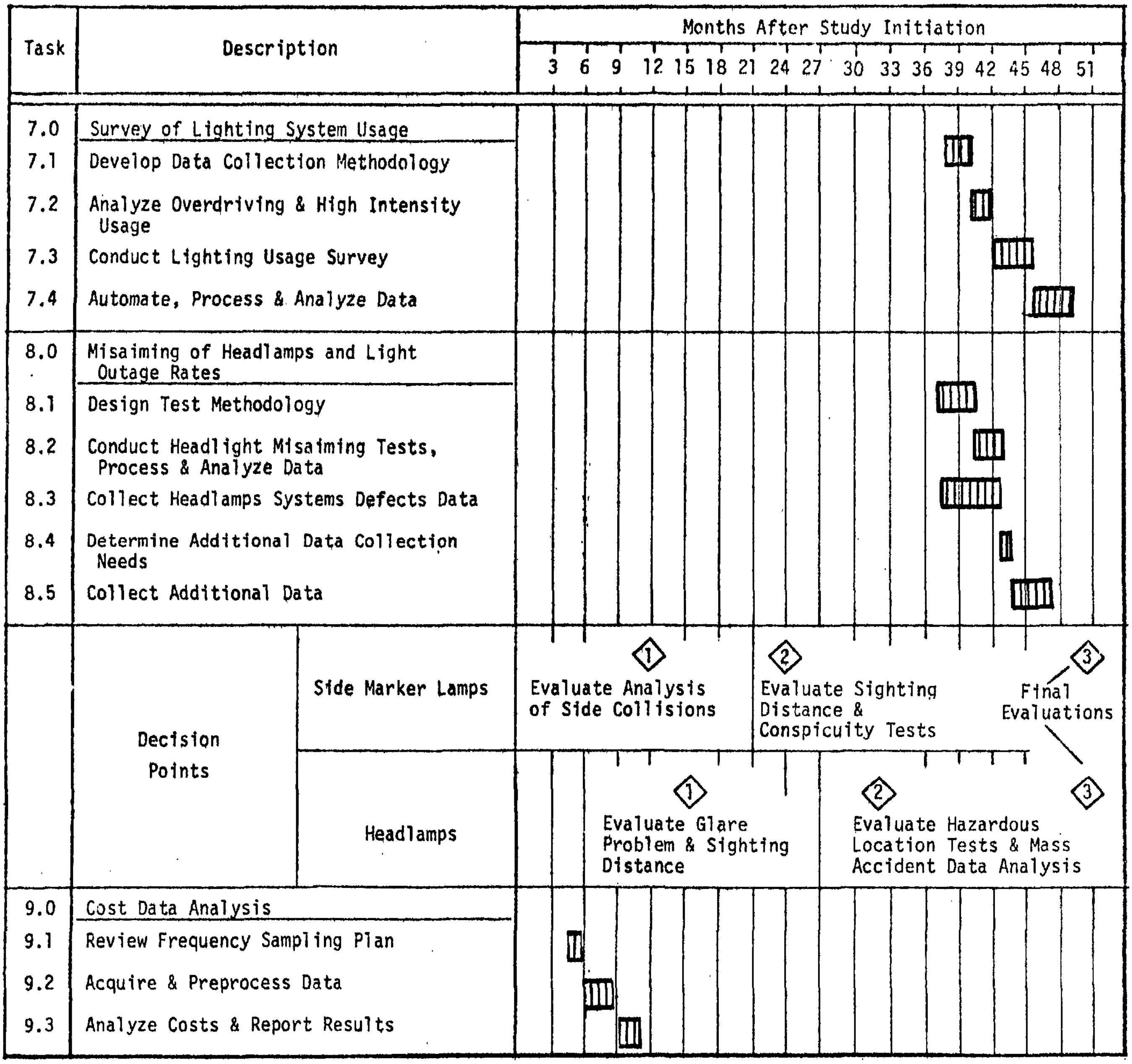


Figure 5-2 (Continued).

Task	Description	Staff Years	Staff Cost ($)	Data Processing Cost ($)	Lab Cost ($)	Equip-ment Cost ($)	Field Data Cost ($)	Total Cost ($)
7.0	Survey of Lighting System Usage							
7.1	Develop Data Collection Methodology	0.1	5K	-	-	-	-	5K
7.2	Analyze Overdriving & High Intensity Usage	0.2	10K	-	-	-	-	10K
7.3	Conduct Lighting Usage Survey	0.6	25K	-	-	4K	20K	49K
7.4	Automate, Process & Analyze Data	0.3	10K	2K	-	-	-	12K
	Total	1.2	50K	2K	-	4K	20K	76K
8.0	Misaiming of Headlamps and Light Outage Rates							
8.1	Design Test Methodology	0.1	5K	-	-	-	-	5K
8.2	Conduct Headlight Misaiming Tests, Process & Analyze Data	0.2	8K	0.5K	-	31K	15K	54.5K
8.3	Collect Headlamps Systems Defects Data	0.1	4K	-	-	-	-	4K
8.4	Determine Additional Data Collection Needs	0.1	5K	0.3K	-	-	-	5.3K
8.5	Collect Additional Data	0.2	7K	0.2K	-	-	10K	17.2K
	Total	0.7	29K	1K	-	31K	25K	86K
9.0	Cost Data Analysis							
9.1	Review Frequency Sampling Plan	0.1	5K	-	-	-	-	5K
9.2	Acquire & Preprocess Data	0.3	15K	0.5K	-	-	-	15.5K
9.3	Analyze Costs & Report Results	0.4	20K	0.5K	-	-	-	20.5K
	Total	0.8	40K	1K	-	-	-	41K
	Grand Total	8.5	407K	18K	14K	43K	75K	557K

Figure 5-3 (Continued).

limited to the survey of lighting system usage (Task 7), a survey and analysis of misaiming of headlamps and brake light indicator outage rates (Task 8) and an additional analysis of mass accident data for the effects of overdriving and glare (Task 6).

Assuming all Tasks are carried out, the estimated resources required for evaluating the effectiveness of and cost of the Standard, amount to $557,000. This figure includes estimated requirements of 8.5 staff-years to carry out the studies.

5.1 Task 1 - Analysis of Mass Accident Data: Side Collisions

Task 1 is concerned with evaluating the performance and effectiveness of the Standard with regard to side marker lamps, using mass accident data. The analysis is directed toward estimating the reduction in the rate of side collisions occurring at dusk and nighttime in vehicles equipped with side marker lamps. The effect of side marker lamps may be greatest when running lights are on, but the headlamps are not. Portions of the following data will be used: HSRI data files, Texas, North Carolina, New York, Virginia and Florida.

It is estimated that six months will be required for the completion of the Task 1 study during the first year. The total resources required for Task 1 are estimated to be $29,000. This total includes accomplishing the Task effort with 0.5 staff-years and $5,000 for data processing.*

5.2 Task 2 - Laboratory Tests of Adverse Weather Effects on Glare (Headlamps)

Task 2 is concerned with examining the performance of high intensity headlamps under adverse environmental conditions. Under conditions of reduced visibility due to rain, snow or fog, the amount of light that is scattered is critical, as well as the light transmitted down the road. Environmental test facilities which can simulate adverse conditions will be located. Various types of headlamps will be obtained and a test rig devised. Using appropriate instruments, comparative tests of headlamps will be conducted under adverse conditions in which beam penetration and backscattering will be measured. This is not envisioned to be a costly or large-scale study.

It is estimated that six months will be required for the completion of the Task 2 work, which would occur during the first year of the evaluation study. The total resources required for Task 2 are estimated to be $46,000. This total includes accomplishing the Task effort with 0.8 staff-years and $6,000 for laboratory costs and equipment costs.

5.3 Task 3 - Sighting Distance Field Study (Side Marker Lamps and Headlamps)

Task 3 is designed to collect data on drivers' nighttime sighting distance as it is affected by headlamp systems, glare and targets. Previous research by medical and traffic safety personnel will be synthesized. A field experiment, which will be designed and tested, shall consider misaiming of headlamps, subject

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*CEM's estimates are based on the assumption that this work will be conducted by a contractor who already has most of the data tapes. We recognize that there is a certain likelihood that this work will be done in-house by NHTSA, with appropriate cost savings.

visual capabilities, headlamp and seat height, glare, and varying targets (no lights, parking light or headlamps). The number of effects which can be included in an expanded field test shall be determined from pilot testing to get preliminary estimates of effects and interactions.

It is estimated that six months will be required for the completion of the Task 3 study. The Task effort can be begun during the first year. The total resources required for Task 3 are estimated to be $112,000. This total includes about 2 staff-years of effort, $5,000 each for equipment and laboratory costs, and $2,000 for data processing.

5.4 Task 4 - Laboratory Tests of Conspicuity of Side Marker Lamps

Task 4 is directed toward determining whether certain side marker lamp designs are more noticeable than other designs. The Task effort will determine how noticeable a side marker lamp on a vehicle is by measuring how intense a slide projected image of the vehicle with a particular lamp must be for a subject to identify the image. The measures of recognition would be the intensity of the vehicle image, the time to recognition at different intensity levels, and the source of identification--side marker lamps or other light sources.

It is estimated that only six months will be required for the completion of the Task 4 study. The Task will not begin until 16 months after initiation of the Standard evaluation. This will allow taking into consideration the results of the analysis of side collisions (Task 1), sighting distance (Task 3) and adverse weather conditions (Task 2). The total resources required for Task 4 are estimated to be $46,000. This total includes accomplishing the Task effort with 0.8 staff-years and $6,000 for equipment and laboratory costs.

5.5 Task 5 - Field Data Collection at Hazardous Locations (Headlamps)

Task 5 is directed toward evaluating the differences in performance between cars with high intensity headlamps *vs.* cars with regular headlamps in hazardous locations at night. A new data collection will be conducted to collect both exposure and disability data (accidents and traffic conflicts). The traffic conflict methodology developed in the 1960's and applied to a variety of problems will be adapted to this study. The initial steps will be to identify and select hazardous locations and train selected data collection teams. Traffic conflict data must be automated prior to data analysis.

It is estimated that twelve months will be required for the completion of the Task 5 study. In addition to a rather lengthy data collection phase, the Task is delayed until 22 months after initiation of work to permit there to be more vehicles with high intensity headlamps. The total resources required for Task 5 are estimated to be $70,000. This total includes about 0.8 staff-years of effort, $30,000 for field data costs and $2,000 for data processing.

5.6 Task 6 - Analysis of Mass Accident Data: Overdriving and Glare (Headlamps)

Task 6 is concerned with evaluating the performance and effectiveness of the Standard with regard to high intensity headlamps, using mass accident data. The study is conducted in two parts. The first part of the mass accident analysis is concerned with estimating the frequency with which drivers are involved in accidents due to overdriving their headlamps. Any reduction in such accidents, due to high intensity headlamp usage will be investigated. The second part of the mass accident analysis is concerned with estimating the frequency of accidents attributed to glare blinding. In each part, portions of the following data will be used: HSRI data files, Texas, North Carolina, New York, Virginia and Florida.

It is estimated that six months will be required for the completion of the initial analysis in Task 6. Since both parts of the analysis require mass accident data that include a sufficient population of vehicles with high intensity headlamps, a reanalysis is scheduled at the end of the fourth year of the study. The total resources required for Task 6 are estimated to be $51,000. This total includes accomplishing the Task effort with 0.9 staff-years and $6,000 for data processing.

5.7 Task 7 - Survey of Lighting System Usage (Side Marker Lamps and Headlamps)

Task 7 is designed to determine the patterns of lighting system usage for both headlamps and parking lights. Factors to be considered include geographical area, highway type, traffic density and following and opposing vehicle behavior. Time of day will be recorded and ambient light conditions monitored. The literature describing previous studies will be reviewed and a data collection methodology established regarding data form, light meters and personnel protocol. Personnel will be trained in selected test areas. The survey data will be computer processed and analyzed. Detailed data on standard errors of usage estimates will be provided.

It is estimated that one year will be required for the completion of the Task 7 study, which can commence early in the fourth year of the study. The total resources required for Task 7 are estimated to be $76,000. This total includes about 1.2 staff-years of effort, $20,000 for field data costs, $4,000 for equipment costs and $2,000 for data processing.

5.8 Task 8 - Misaiming of Headlamps and Light Outage Rate

Task 8 is directed toward (1) determining the prevalence and degree of misaiming of headlamps in the vehicle population; and (2) conducting a survey to estimate how often vehicle lighting systems are totally or partially failed. In the first part of the study, the literature will be reviewed to determine factors relevant to headlamp misaiming and the size of effects. Based on the review, a test methodology will be developed that will include test and equipment required, personnel training, site selection and data recording. Results of the misaiming test will be utilized in the second part of the study.

In the second part of the study, literature and data on defect and outage rates of headlamp systems will be collected. If required, the need for additional data will be specified and the data collection will be executed and analyzed. The costing of this Task assumes the collection and analysis of additional data.

It is estimated that nine months will be required for the completion of the Task 8 study, even assuming that additional data on defect and outage rates of headlamp systems must be collected in the second part of the Task effort. The Task 8 study will not begin until the beginning of the fourth year of the overall evaluation study. This will permit a sufficient sample of vehicles with high intensity headlamps. The total resources required for Task 8 are estimated to be $86,000. This total includes 0.7 staff-years of effort, $31,000 for equipment, $25,000 for field data costs and $1,000 for data processing.

5.9 Task 9 - Cost Data Analysis

Task 9 is concerned with the determination of direct costs to implement FMVSS 108. Cost categories are confined to direct manufacturing, indirect manufacturing, capital investment (including testing), manufacturer's markup, dealer's markup and taxes.* A frequency sampling plan to determine the costs of side marker lamps has been developed which assumes that the manufacturers' cost of compliance varies according to manufacturer or market class. Other factors will not be considered. The two levels of interest are:

1. Manufacturer: GM, Ford, Chrysler, AMC, VW, Toyota, Datsun.
2. Size: Sports type, Subcompact, Compact, Intermediate, Full Size, Medium and Luxury.

The plan described above is suitable for side marker lamps. Since not all models will have, and perhaps not all manufacturers will offer models with high intensity headlamps, a different sampling plan to determine the incremental cost of the high intensity headlamps may be necessary. Initially, we suggest that costs be collected on one model with the high intensity headlamps from each major American manufacturer. If these costs differ much from one another, then more detailed investigation may be worthwhile.

The cost of compliance is of interest in two aspects: total cost and cost per vehicle. For total cost, models should be assigned on the basis of their dollar share of the market, and for per vehicle costs, models should be chosen on the basis of vehicle share of the market. In this way, the standard error of the overall cost estimates is minimized.

Task 9 will be completed in six months during the first year of the study. It is estimated that the total resources required are $41,000; this includes 0.8 staff-years of effort and $1,000 for computer processing.

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*These are the cost categories specified by NHTSA. One should realize that manufacturers' and dealers' markups are not easily obtainable for specific models (if at all). The overall "markup" is the difference between the actual price set at the time of sale, largely according to market conditions, and the total manufacturing costs, which are to some extent determined years in advance, when the car is designed, and to some extent by the volume actually produced, which results from the market conditions.

Taxes play a different role; some are a factor which can enter the cost calculation (e.g., property taxes). Income taxes, however, are levied on profit, which is a residual and not predictable (if a manufacturer operates at a loss, no income taxes are due).

APPENDIX A

FEDERAL MOTOR VEHICLE SAFETY STANDARD 108:

SIDE MARKER LAMPS AND HIGH INTENSITY HEADLAMPS (ONLY)

MOTOR VEHICLE SAFETY STANDARD NO. 108

Lamps, Reflective Devices, and Associated Equipment—Passenger Cars, Multipurpose Passenger Vehicles, Trucks, Buses, Trailers and Motorcycles

(Docket No. 69–18)

S1. Purpose and scope. This standard specifies requirements for original and replacement lamps, reflective devices, and associated equipment necessary for signaling and for the safe operation of motor vehicles during darkness and other conditions of reduced visibility.

S2. Application. This standard applies to passenger cars, multipurpose passenger vehicles, trucks, buses, trailers (except pole trailers and trailer converter dollies), and motorcycles, and to lamps, reflective devices, and associated equipment for replacement of like equipment on vehicles to which this standard applies.

S3. Definitions. "Flash" means a cycle of activation and deactivation of a lamp by automatic means continuing until stopped either automatically or manually.

"Speed attainable in 1 mile" means the speed attainable by accelerating at maximum rate from a standing start for 1 mile on a level surface.

S4. Requirements.

S4.1 Required motor vehicle lighting equipment.

S4.1.1 Except as provided in succeeding paragraphs of S4.1.1, each vehicle shall be equipped with at least the number of lamps, reflective devices and associated equipment specified in Tables I and III, as applicable. Required equipment shall be designed to conform to the SAE Standards or Recommended Practices referenced in those tables. Table I applies to multipurpose passenger vehicles, trucks, trailers, and buses, 80 or more inches in overall width. Table III applies to passenger cars and motorcycles and to multipurpose passenger vehicles, trucks, trailers, and buses less than 80 inches in overall width.

S4.1.1.1 [A truck tractor need not be equipped with turn signal lamps mounted on the rear if the turn signal lamps at or near the front are so constructed (double-faced) and so located that they meet the requirements for double-faced turn signals specified in SAE Standard J588e, "Turn Signal Lamps," September 1970. (41 F.R. 765—January 5, 1976. Effective: 1/5/76)]

S4.1.1.2 A truck tractor need not be equipped with any rear side marker devices, rear clearance lamps, and rear identification lamps.

S4.1.1.3 Intermediate side marker devices are not required on vehicles less than 30 feet in overall length.

S4.1.1.4 [Reflective material conforming to Federal Specification L–S–300, "Sheeting and Tape, Reflective; Nonexposed Lens, Adhesive Backing," September 7, 1965, may be used for side reflex reflectors if this material, as used on the vehicle, meets the performance standards in Table I of SAE Standard J594e, Reflex Reflectors, March 1970. (41 F.R. 50826—November 18, 1976. Effective: 11/18/76)]

S4.1.1.5 The turn signal operating unit on each passenger car, and multipurpose passenger vehicle, truck, and bus less than 80 inches in overall width manufactured on or after January 1, 1973, shall be self-cancelling by steering wheel rotation and capable of cancellation by a manually operated control.

S4.1.1.6 Each stop lamp on any motor vehicle manufactured between January 1, 1973, and September 1, 1978, may be designed to conform to SAE Standard J586b, *Stop Lamps*, June 1966. It shall meet the photometric minimum candlepower requirements for Class A red turn signal lamps specified in SAE Standard J575d, *Tests for Motor Vehicle Lighting Devices and Components*, August 1967. Each such lamp on a passenger car and on a multipurpose passenger vehicle, truck, trailer or bus less than 80 inches in overall width shall have an effective projected luminous area not less than 3½ square inches. If multiple compartment lamps or multiple lamps are used, the effective projected luminous area of each compartment or lamp shall be not less than 3½ square inches; however, the photometric requirements may be met by a combination of compartments or lamps.

S4.1.1.7 Each turn signal lamp on any motor vehicle except motorcycles, manufactured between January 1, 1972, and September 1, 1978, may be designed to conform to SAE Standard J588d, *Turn Signal Lamps*, June 1966, and shall meet the photometric minimum candlepower requirements for Class A turn signal lamps specified in SAE Standard J575d, *Tests for Motor Vehicle Lighting Devices and Components*, August 1967. Each such lamp on a passenger car and on a multipurpose passenger vehicle, truck, trailer or bus less than 80 inches in overall width shall have an effective projected luminous area not less than 3½ square inches. If multiple compartment lamps or multiple lamps are used, the effective projected luminous area of each compartment or lamp shall be not less than 3½ square inches; however, the photometric requirements may be met by a combination of compartments or lamps. Each such lamp on a multipurpose passenger vehicle, truck, trailer or bus 80 inches or more in overall width shall have an effective projected luminous area not less than 12 square inches.

S4.1.1.8 For each passenger car, and each multipurpose passenger vehicle, truck, trailer, and bus of less than 80 inches in overall width, the photometric minimum candlepower requirements for side marker lamps specified in SAE Standard J592e, "Clearance, Side Marker, and Identification Lamps," July 1972, may be met for all inboard test points at a distance of 15 feet from the vehicle and on a vertical plane that is perpendicular to the longitudinal axis of the vehicle and located midway between the front and rear side marker lamps.

S4.1.1.9 Boat trailers need not be equipped with both front and rear clearance lamps, provided an amber (to front) and red (to rear) clearance lamp is located at or near the midpoint on each side of the trailer so as to indicate its extreme width.

S4.1.1.10 Multiple license plate lamps and backup lamps may be used to fulfill the requirements of the SAE Standards applicable to such lamps referenced in Tables I and III.

S4.1.1.11 A parking lamp is not required to meet the minimum photometric values at each test point specified in Table 1 of SAE Standard J222, "Parking Lamps (Position Lamps)," if the sum of the candlepower measured at the test points within the groups listed in Figure 1 is not less than the sum of the candlepower values for such test points specified in J222.

S4.1.1.12 A taillamp, stop lamp, or turn signal lamp is not required to meet the minimum photometric values at each test point specified in the referenced SAE Standards, if the sum of the candlepower measured at the test points is not less than that specified for each group listed in Figure 1, or for motorcycle turn signal lamps, not less than one-half of such sum.

S4.1.1.13 (Deleted, 38 F. R. 16875—June 27, 1973. Effective: 7/23/73)

S4.1.1.14 (Deleted, 38 F.R. 16875—June 27, 1973. Effective: 7/23/73)

S4.1.1.15 (Deleted, 38 F.R. 16875—June 27, 1973. Effective: 7/23/73)

S4.1.1.16 All passenger cars and multipurpose passenger vehicles, trucks, and buses of less than 80 inches overall width shall be equipped with turn signal operating units designed to complete a durability test of 100,000 cycles.

S4.1.1.17 A trailer that is less than 30 inches in overall width may be equipped with only one of each of the following lamps and reflective devices, located at or near its vertical centerline: Tail lamp, stop lamp, and rear reflex reflector.

S4.1.1.18 A trailer that is less than 6 feet in overall length, including the trailer tongue, need not be equipped with front side marker lamps and front side reflex refectors.

S4.1.1.9 A lamp manufactured on or after January 1, 1974, and designed to use a type of bulb that has not been assigned a mean spherical candlepower rating by its manufacturer and is not listed in SAE Standard J573d, "Lamp Bulbs and Sealed Units," December 1968, shall meet the applicable requirements of this standard when used with any bulb of the type specified by the lamp manufacturer, operated at the bulb's design voltage. A lamp that contains a sealed-in bulb shall meet these requirements with the bulb operated at the bulb's design voltage.

S4.1.1.20 Except for a lamp having a sealed in bulb, a lamp manufactured on or after January 1, 1974 shall meet the applicable requirements of this standard when tested with a bulb whose filament is positioned within ±.010 inch of the nominal design position specified in SAE Standard J573d, "Lamp Bulbs and Sealed Units," December 1968, or specified by the bulb manufacturer.

S4.1.1.21 Instead of a headlighting system of two Type 1 headlamps and two Type 2, 5¾-inch headlamps, a vehicle manufactured on or after January 1, 1974, may be equipped with a headlighting system of two Type 1A headlamps

Groups	Test Points Deg	Parking Lamps	Group Totals, CP								
			Tail Lamps			Red Stop and Turn Signal Lamps			Yellow Turn Signal Lamps		
			One	Two	Three	One	Two	Three	One	Two	Three
1	20L-5U 20L-H 20L-5D 10L-10U 10L-10D	2.8	1.6	2.7	3.8	55	66	80	135	165	190
2	10U-V 5U-10L 5U-10R	2.4	2.1	3.6	5.5	85	100	115	210	251	290
3	10L-H 5L-5U 5L-5D	4.2	3.4	5.3	8.0	140	167	195	350	420	490
4	5U-V H-5L H-V H-5R 5D-V	16.8	9.6	16.5	24.0	380	449	520	950	1,130	1,295
5	5R-5U 5R-5D 10R-H	4.2	3.4	5.3	8.0	140	167	195	350	420	490
6	5D-10L 5D-10R 10D-V	2.4	2.1	3.6	5.5	85	100	115	210	251	290
7	10R-10U 10R-10D 20R-5U 20R-H 20R-5D	2.8	1.6	2.7	3.8	55	66	80	135	165	190
Maximum-Rear Lamps Only			15	20	25	300	360	420	900	900	900

FIGURE 1.—Grouped photometric minimum candlepower requirements for devices using one, two, or three separately lighted compartments, or for one, two, or three lamps used in a single design location to perform a single function.

and two Type 2A headlamps, that meet the following requirements.

(a) Each Type 1A headlamp and Type 2A headlamp shall be designed to conform to the requirements for a Type 1 headlamp and Type 2, 5¾-inch headlamp, respectively, as specified in any SAE Standard or Recommended Practice, referenced or subreferenced by Tables I and III, except as provided below.

(b) Each Type 1A and Type 2A headlamp shall be designed to conform to the applicable dimensional requirements and specifications of Figure 2. At a voltage of 12.8 volts, the maximum design wattage with an allowable tolerance of plus 7.5 percent shall be 50 watts for a Type 1A headlamp and 60 watts for each filament of a Type 2A headlamp.

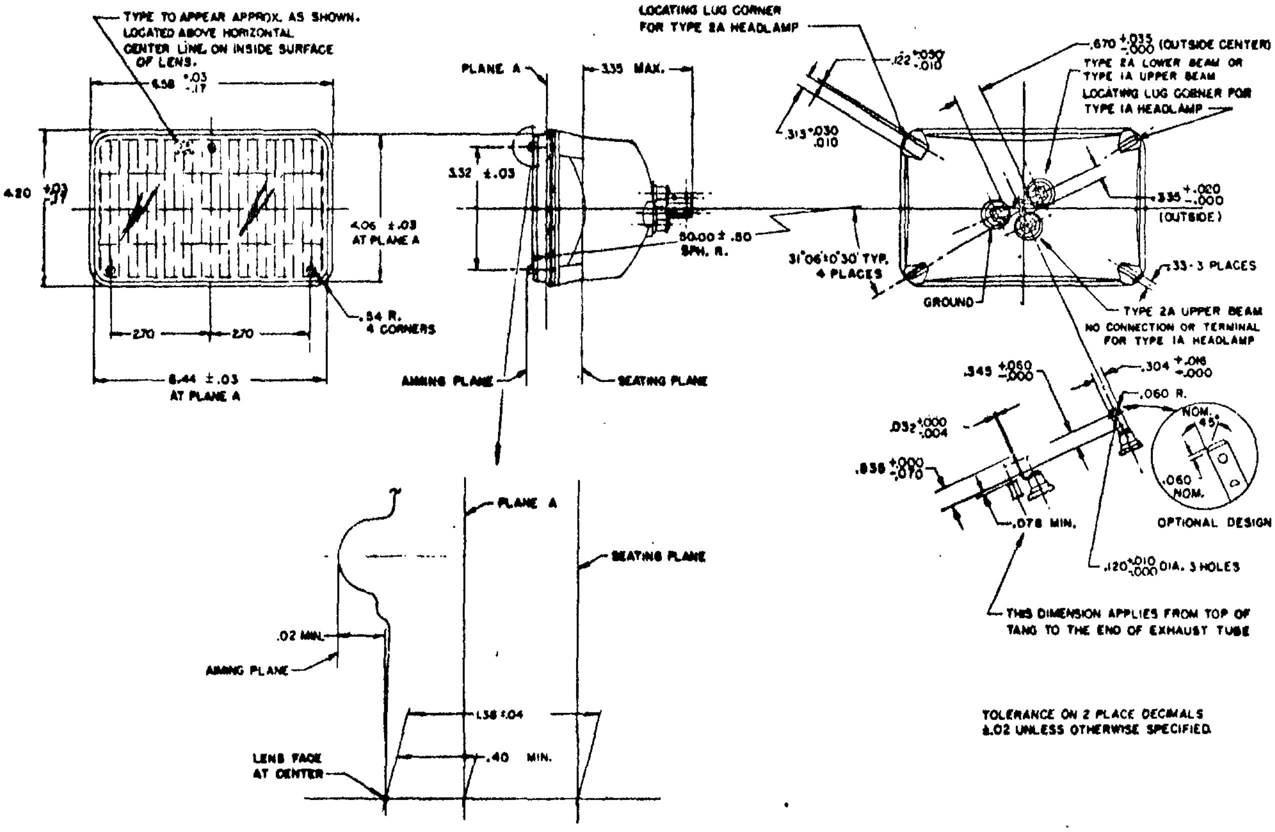
(c) The following SAE Standards and Recommended Practices, or portions thereof, do not apply:

(i) SAE Standard J571b, "Dimensional Specifications for Sealed Beam Headlamp Units," April 1965.

(ii) SAE Standard J573d, "Lamp Bulbs and Sealed Units," December 1968.

(iii) Figure 1, SAE Recommended Practice J602, "Headlamp Aiming Device for Mechanically Aimable Sealed Beam Headlamp Units," August 1963.

(iv) Paragraph 2 of "Retaining Ring Requirements," and the paragraph "Proper Seating of Sealed Beam Unit", SAE Standard J580a, "Sealed Beam Headlamp", June 1966.



TOLERANCE ON 2 PLACE DECIMALS ±.02 UNLESS OTHERWISE SPECIFIED.

FIGURE 2
RECTANGULAR HEADLAMP SPECIFICATIONS

S4.1.1.22 A backup lamp is not required to meet the minimum photometric values at each test point specified in Table I of SAE Standard J593c "Backup Lamps" if the sum of the candlepower measured at the test points within each group listed in Figure 3 is not less than the group totals specified in that figure.

S4.1.1.23 Variable load turn signal flashers shall comply with voltage drop and durability requirements with the maximum design load connected and shall comply with starting time, **flash** rate, and percent current "on" time requirements both with the minimum and with the maximum design load connected.

Group	*Test point, deg*	*Total for Group, cd (see notes a, b)*
1[a]	45L–5U	45
	45L–H	
	45L–5D	
2[a]	30L–H	50
	30L–5D	
3	10L–10U	100
	10L–5U	
	V–10U	
	V–5U	
	10R–10U	
	10R–5U	
4	10L–H	360
	10L–5D	
	V–H	
	V–5D	
	10R–H	
	10R–5D	
5[a]	30R–H	50
	30R–5D	
6[a]	45R–5U	45
	45R–H	
	45R–5D	

[a] When two lamps of the same or symmetrically opposite design are used, the reading along the vertical axis and the averages of the readings for the same angles left and right of vertical for one lamp shall be used to determine compliance with the requirements. If two lamps of differing designs are used, they shall be tested individually and the values added to determine that the combined units meet twice the candela requirements.

[b] When only one backup lamp is used on the vehicle, it shall be tested to twice the candela requirements.

FIGURE 3—Minimum Luminous Intensity Requirements for Backup Lamps

S4.1.1.24 The lowest voltage drop for turn signal flashers and hazard warning signal flashers measured between the input and load terminals shall not exceed 0.8 volt.

[S4.1.1.25 Reserved. (42 F.R. 7140—February 7, 1977. Effective: 2/7/77)**]**

S4.1.1.26 A motor-driven cycle whose speed attainable in 1 mile is 30 mph or less need not be equipped with turn signal lamps.

S4.1.1.27 A motor-driven cycle whose speed attainable in 1 mile is 30 mph or less may be equipped with a stop lamp whose photometric output for the groups of test points specified in Figure 1 is at least one-half of the minimum values set forth in that figure.

S4.1.1.28 Each taillamp on any motor vehicle manufactured before September 1, 1978, may be designed to conform to SAE Standard J585c, *Tail Lamps*, June 1966.

S4.1.1.29 Each turn signal lamp on a motorcycle manufactured between January 1, 1973, and September 1, 1978, may be designed to conform to SAE Standard J588d, *Turn Signal Lamps*, June 1966.

S.4.1.1.30 Except as provided in paragraph S4.1.1.12 of this standard, each turn signal lamp on a motorcycle shall meet one-half of the minimum photometric values at each test point specified for Class A turn signal lamps in SAE Standard J575d, *Tests for Motor Vehicle Lighting Devices and Components*, August 1967, or in SAE Standard J588e, *Turn Signal Lamps*, September 1970, as applicable.

S4.1.1.31 Each turn signal lamp on a motorcycle manufactured on and after January 1, 1973, shall have an effective projected luminous area not less than 3½ square inches.

S4.1.1.32 Note 6 of Table 1 in SAE Standard J588e, *Turn Signal Lamps*, September 1970, does not apply. A stop lamp that is not optically combined with a turn signal lamp shall remain activated when the turn signal is flashing.

S4.1.1.33 Headlamps may conform to SAE Standard J579c, *Sealed Beam Headlamp Units for Motor Vehicles*, December 1974, except that:

(a) In Table I of SAE Standard J579c, the maximum candela at any test point shall not exceed 37,500;

(b) In Table II of SAE Standard J579c, the combined maximum candela at any test point shall not exceed 37,500; and

(c) At a voltage of 12.8 volts, the maximum design wattage, with an allowable tolerance of plus 7.5 percent, shall be as follows: 50 watts for Type 1 (5¾-inch); 37.5 watts for Type 2 (5¾-inch) high beam; and 60 watts for Type 2 (5¾-inch) low beam, Type 2 (7-inch) low beam, and Type 2 (7-inch) high beam.

[**S4.1.1.34** (a) Instead of a headlighting system employing two Type 2, 7-inch headlamp units, a passenger car, multipurpose passenger vehicle, truck, or bus manufactured on or after November 1, 1976, may be equipped with a system of two Type 2B headlamp units. A motorcycle manufactured on or after November 1, 1976, may be equipped with a system of either one or two Type 2B headlamp units. Each Type 2B headlamp unit shall be designed to conform to SAE Recommended Practice J1132, "142mm × 200mm Sealed Beam Headlamp Unit," January 1976, except that Paragraph 5 titled "Service Performance" is not applicable.

(b) Applicable referenced and subreferenced SAE Standards and Recommended Practices not specifically included in SAE J1132 are those published in the 1976 edition of the SAE Handbook. (41 F.R. 46437—October 21, 1976. Effective: 11/1/76)]

S4.1.2 Plastic materials used for optical parts such as lenses and reflectors shall conform to SAE Recommended Practice J576c, May 1970, except that:

(a) Plastic materials manufactured before January 1, 1976, may conform to SAE J576b, August 1966;

(b) Plastic lenses used for inner lenses or those covered by another material and not exposed directly to sunlight shall meet the requirements of paragraphs 3.4 and 4.2 of SAE J576b, or J576c, as applicable, when covered by the outer lens or other material;

(c) After the outdoor exposure test, the haze and loss of surface luster of plastic materials used for lamp lenses shall not be greater than 30 percent haze as measured by ASTM-1003-61, "Haze and Luminous Transmittance of Transparent Plastics;" and

(d) After the outdoor exposure test, plastic materials used for reflex reflectors shall meet the appearance requirements of paragraph 4.2.2 of SAE J576b or J576c as applicable.

S4.1.3 No additional lamp, reflective device, or other motor vehicle equipment shall be installed that impairs the effectiveness of lighting equipment required by this standard.

S4.1.4 Each school bus shall be equipped with a system of either:

(a) Four red signal lamps designed to conform to SAE Standard J887, "School Bus Red Signal Lamps," July 1964, and installed in accordance with that standard; or

(b) Four red signal lamps designed to conform to SAE Standard J887, "School Bus Red Signal Lamps," July 1964, and four amber signal lamps designed to conform to that standard, except for their color, and except that their candlepower shall be at least 2½ times that specified for red signal lamps. Both red and amber lamps shall be installed in accordance with SAE Standard J887, except that:

(i) Each amber signal lamp shall be located near each red signal lamp, at the same level, but closer to the vertical centerline of the bus; and

(ii) The system shall be wired so that the amber signal lamps are activated only by manual or foot operation, and if activated, are automatically deactivated and the red signal lamps automatically activated when the bus entrance door is opened.

S4.1.5 The color in all lighting equipment covered by this standard shall be in accordance with SAE Standard J578a, April 1965, "Color Specification for Electric Signal Lighting Devices."

S4.5. Special wiring requirements.

S4.5.1 Each vehicle shall have a means of switching between lower and upper headlamp beams that conforms to SAE Recommended Practice J564a, "Headlamp Beam Switching," April 1964, or to SAE Recommended Practice J565b, "Semi-Automatic Headlamp Beam Switching Devices," February 1969.

S4.5.2 Each vehicle shall have a means for indicating to the driver when the upper beams of the headlamps are on that conforms to SAE Recommended Practice J564a, April 1964, except that the signal color need not be red.

S4.5.3 The taillamps on each vehicle shall be activated when the headlamps are activated in a steady-burning state.

S4.5.4 The stop lamps on each vehicle shall be activated upon application of the service brakes.

S4.5.5 The vehicular hazard warning signal operating unit on each vehicle shall operate independently of the ignition or equivalent switch, and when activated, shall cause to flash simultaneously sufficient turn signal lamps to meet, as a minimum, the turn signal lamp photometric requirements of this standard.

S4.5.6 Each vehicle equipped with a turn signal operating unit shall also have an illuminated pilot indicator. Failure of one or more turn signal lamps to operate shall be indicated in accordance with SAE Standard J588e, "Turn Signal Lamps," September 1970, except where a variable-load turn signal flasher is used on a truck, bus, or multipurpose passenger vehicle 80 or more inches in overall width, on a truck that is capable of accommodating a slide-in camper, or on any vehicle equipped to tow trailers.

S4.5.7 On all passenger cars, and motorcycles, and multipurpose passenger vehicles, trucks, and buses of less than 80 inches overall width:

(a) When the parking lamps are activated, the taillamps, license plate lamps, and side marker lamps shall also be activated; and

(b) When the headlamps are activated in a steady-burning state, the taillamps, parking lamps, license plate lamps and side marker lamps shall also be activated.

S4.6 When activated:

(a) Turn signal lamps, hazard warning signal lamps, and school bus warning lamps shall flash; and

(b) All other lamps shall be steady-burning, except that means may be provided to flash headlamps and side marker lamps for signaling purposes.

S4.7 Replacement Equipment

S4.7.1 Each lamp, reflective device, or item of associated equipment manufactured to replace any lamp, reflective device, or item of associated equipment on any vehicle to which this standard applies, shall be designed to conform with this standard.

S4.7.2 Each lamp, reflective device, or item of associated equipment to which section S4.7.1 applies may be labeled with the symbol DOT, which shall constitute a certification that it conforms to applicable Federal motor vehicle safety standards.

S5. Subreferenced SAE Standards and Recommended Practices.

S5.1 SAE Standards and Reccommended Practices subreferenced by the SAE Standards and Recommended Practices included in Tables I and III and paragraphs S4.1.4 and S4.5.1 are those published in the 1970 edition of the SAE Handbook, except that the SAE Standard referred to as "J599" is J599c, *Lighting Inspection Code*, March 1973, and the subreferenced SAE Standard referred to as "J575" is J575c, *Tests for Motor Vehicle Lighting Devices and Components*, August 1970, for tail lamps, stop lamps, and turn signal lamps designed to conform to SAE Standard J585d, J586c, and J588e, respectively.

S5.2 Requirements of SAE Standards incorporated by reference in this standard, other than J576b and J576c, do not include tests for warpage of devices with plastic lenses.

S4.2. Other requirements.

S4.2.1 The words "it is recommended that," "recommendations," or "should be" appearing in any SAE Standard or Recommended Practice referenced or subreferenced in this standard shall be read as setting forth mandatory requirements, except that the aiming pads on the lens face and the black area surrounding the signal lamp, recommended in SAE Standard J887, "School Bus Red Signal Lamps," July 1964, are not required.

S4.3. Location of required equipment.

S4.3.1 [Except as provided in succeeding paragraphs of S4.3.1, each lamp, reflective device, and item of associated equipment shall be securely mounted on a rigid part of the vehicle other than glazing that is not designed to be removed except for repair, in accordance with the requirements of Table I or III and in locations specified in Table II (multipurpose passenger vehicles, trucks, trailers, and buses 80 or more inches in overall width) or Table IV (all passenger cars, and motorcycles, and multipurpose passenger vehicles, trucks, trailers, and buses less than 80 inches in overall width), as applicable. (41 F.R. 50826—November 18, 1976. Effective: 11/18/76)]

S4.3.1.1. [Except as provided in S4.3.1.1.1, each lamp and reflective device shall be located so that it meets the visibility requirements specified in any applicable SAE Standard or Recommended Practice. In addition, no part of the vehicle shall prevent a parking lamp, taillamp, stop lamp, turn signal lamp, or backup lamp from meeting its photometric output at any applicable group of test points specified in Figures 1 and 3, or prevent any other lamp from meeting the photometric output at any test point specified in any applicable SAE Standard or Recommended Practice. However, if motor vehicle equipment (e.g., mirrors, snow plows, wrecker booms, backhoes, and winches) prevents compliance with this paragraph by any required lamp or reflective device, an auxiliary lamp or device meeting the requirements of this paragraph shall be provided. (40 F.R. 54427—November 24, 1975. Effective: 11/24/75)]

[**S4.3.1.1.1** Clearance lamps may be mounted at a location other than on the front and rear if necessary to indicate the overall width of a vehicle, or for protection from damage during normal operation of the vehicle, and at such a location they need not be visible at 45 degrees inboard. (40 F.R. 54427—November 24, 1975. Effective: 11/24/75)]

S4.3.1.2 On a truck tractor, the red rear reflex reflectors may be mounted on the back of the cab, at a minimum height not less than 4 inches above the height of the rear tires.

S4.3.1.3 On a trailer, the amber front side reflex reflectors and amber front side marker lamps may be located as far forward as practicable exclusive of the trailer tongue.

S4.3.1.4 When the rear identification lamps are mounted at the extreme height of a vehicle, rear clearance lamps need not meet the requirement of Table II that they be located as close as practicable to the top of the vehicle.

S4.3.1.5 The center of the lens referred to in SAE Standard J593c, "Backup Lamps," February 1968, is the optical center.

S4.3.1.6 On a truck tractor, clearance lamps mounted on the cab may be located to indicate the width of the cab, rather than the overall width of the vehicle.

S4.3.1.7 The requirement that there be not less than 4 inches between a front turn signal lamp and a low-beam headlamp, specified in SAE Standard J588e, "Turn Signal Lamps," September 1970, shall not apply if the sum of the candlepower values of the turn signal lamp measured at the test points within each group listed in Figure 1 is not less than two and one-half times the sum specified for each group for yellow turn signal lamps.

S4.4. Equipment combinations.

S4.4.1 Two or more lamps, reflective devices, or items of associated equipment may be combined if the requirements for each lamp, reflective device, and item of associated equipment are met, except that no clearance lamp may be combined optically with any taillamp or identification lamp.

Interpretation

(1) The term "overall width" refers to the nominal design dimension of the widest part of the vehicle, exclusive of signal lamps, marker lamps, outside rearview mirrors, flexible fender extensions, and mud flaps, determined with doors and windows closed, and the wheels in the straight-ahead position.

(2) Paragraph S3.1 and Tables I and III of § 571.108 as amended (32 F.R. 18033, Dec. 16, 1967), specify that certain lamp assemblies shall conform to applicable SAE Standards. Each of these basically referenced standards subreferences both SAE Standard J575 (tests for motor vehicle lighting devices and components) which in turn references SAE Standard J573 on bulbs, and SAE Standard J567 on bulb sockets.

(3) Paragraph C of SAE Standard J575 states in part: "Where special bulbs are specified, they should be submitted with the devices and the same or similar bulbs used in the tests and operated at their rated mean spherical candlepower." The Administrator has determined that this provision of SAE Standard J575 permits the use of special bulbs, including tubular-type bulbs, which do not conform to the detailed requirements of Table I of SAE Standard J573. It follows that the sockets for special bulbs need not conform to the detailed requirements of SAE Standard J567. These provisions for special bulbs in no way except the lamp assemblies from meeting all performance requirements specified in Federal Standard No. 108, including those specified in the basically referenced SAE Standards, and in the subreferenced SAE Standard J575.

35 F.R. 16842
October 31, 1970

APPENDIX B

DISCUSSION OF STATISTICAL TECHNIQUES

DISCUSSION OF STATISTICAL TECHNIQUES

INTRODUCTION

The field of statistics has grown out of a variety of disciplines such as political science, economics, biology, geology and agricultural genetics. Statistical techniques address a variety of problems faced by each of these disciplines. During this century, various mathematical foundations have been constructed for the field of statistics and many of the seemingly disparate techniques have been shown to be closely related in terms of their mathematical content. This similarity between techniques developed in different fields is due to the underlying similarity of the problems addressed in these fields: namely, successfully making inferences about a larger parent population, given the tremendous variation in the sampled data.

Statistics involves reducing the complexity of large amounts of data, so hypothesized relationships can be tested, while controlling for possible sources of error and extraneous variation. Some researchers emphasize statistical use of sample characteristics to make inferences about population characteristics. Some emphasize statistical use of hypothesized models and the concomitant techniques of parameter estimation, parameter testing and assessment of "goodness of fit."

Irrespective of particular emphasis, statistics is useful for the simple reason that many of the facts we wish to know are only knowable at great cost in time and effort and so we are *forced* to use a "sample" of manageable size to provide us with an approximate understanding of the situation. Economically, statistics allows us to arrive at highly probable answers by analyzing only a small subset of information on the total population considered.

In a field such as statistics where techniques have been developed from many different perspectives,it is not surprising to find that supposedly different techniques overlap in applicability and indeed sometimes may be shown to be equivalent. With the advent of readily available computers and statistical software, numerous investigators in the life sciences and natural sciences are discovering for themselves the usefulness of using a multiplicity of techniques to explore their data. For, while it is the rare data set that can satisfy all the technical assumptions of any given statistical technique, it is *also* the rare statistical technique that is so "unstable" as to demand that all of its technical assumptions be met exactly. This property of being "robust," i.e., continuing to produce reasonable answers under a variety of unreasonable conditions, is enjoyed by many of the statistical techniques that are applicable to the data bases available for the evaluation of the effectiveness of Federal Motor Vehicle Safety Standards (FMVSS). Indeed, today many of the classical statistical techniques are being rebuilt in more robust form and there are available a variety of robust modifications to the processes of estimation that are amenable to any linear model situation, e.g., regression, analysis of variance, and loglinear analysis [1].

Besides both the creation of software packages supplying a variety of high quality statistical procedures and the development of robust techniques of inference, the last decade has also seen the development of new techniques, new software and, indeed, a new way of thinking about data analysis. John Tukey was one of the first to call attention to the split in statistical analysis between those textbook techniques that are perfect for well controled experiments and the less formal techniques and procedures that are useful for undesigned experiments or when simply "exploring" new data. Tukey christened the former "confirmatory data analysis" and the latter "exploratory data analysis." The original analogy used to contrast the two sets of attitudes was to point to the differences between formal court proceedings used to arrive at "the truth" *versus* the more intuitive and less formal inferential behavior that a good detective, such as Sherlock Holmes, would allow himself in the process of collecting evidence that might or might not be used in a formal court proceeding at some later data. While exploratory data analysis is never an answer in itself, experience with its techniques has shown that it has unique value to the researcher when faced with large, complex and perhaps faulty data bases. An introduction to the wealth of techniques in exploratory data analysis is available from Tukey's text and computer software for many of these techniques exists at a number of the larger university computer centers [2].

Recently the field of data analysis (as differentiated from formal mathematical statistics) has also been influenced by the development of useable "Bayesian" and pseudo-Bayesian techniques of inference. While these techniques are firmly rooted in a purely mathematical foundation of inference, their acceptance has been limited, due to the continuing controversy among statisticians as to their appropriateness in various situations. The nub of the problem is that Bayesian techniques make a point of allowing prior information (sometimes subjectively arrived at) to influence the results of estimation, model building and, indeed, the complete process of inference from data. Such honesty about the use of subjective information obviously is disturbing to those who feel that data analysis both can and should be a totally objective process. However, the benefits of Bayesian and pseudo-Bayesian techniques are quite attractive and their use by a researcher in dealing with a real analysis problem should not be seen as an endorsement of the full Bayesian philosophy of inference. Bayesian-like techniques of data smoothing and of simultaneously estimating many parameters are of real value when trying to reduce the complexity and dimensionality of multidimensional data sets. Similarly, such techniques allow a researcher to incorporate previous data bases into the analysis of his present data base in a logical, mathematically tractable and theoretically desirable way. Most classical statistical procedures are hard put to find a way to use such prior information when exploring a new data base.

When addressing the particular problems of measuring the effectiveness of various FMVSSs using the existing data bases, it would be unwise to become too attached to any one approach to the analysis. Given the variety of data bases and the variety of problems each data base presents, only a healthy electicism towards statistical method and philosophy will provide the "robustness" of inference and thoroughness of analysis necessary for adequate assessment of effectiveness. The following discussion of different statistical techniques is provided in the spirit of fostering such healthy electicism. Each technique is applicable to some of the existing data sets and, in fact, it would often be valuable to explore a particular data base using many such techniques jointly or sequentially. For example, many data bases provide the researcher with multidimensional tables of frequency counts in a number of categories. Such data are amenable to many of the exploratory data analytic techniques to look for potential structure; they are also amenable to a number of data reduction techniques such as principal component analysis and factor analysis in an effort to reduce its complexity and dimensionality; more formally, the data or some transformation of the data may be modeled, explored and smoothed using loglinear analysis. Similar analyses may be tried using classical linear models methods and "trusting" in the robustness of such methods [3]; finally, Bayesian-like techniques are applicable when such tables of counts are updated periodically and one wishes to use the structure of past tables to influence the analysis of the most recent table.

The point is that a thorough assessment of effectiveness demands a willingness to apply many techniques to each collection of data and to assess findings of each technique in light of the quirks of the data and in light of the findings of other techniques.

This appendix is intended to provide an introduction to the concepts, vocabulary and logic of some of the many statistical and data analytic techniques that are applicable to the evaluation of the effectiveness of Federal Motor Vehicle Safety Standards.

References

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2. Tukey, J.W. *Exploratory Data Analysis*, Addison-Wesley, Menlo Park, California, 1977.

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ANALYSIS OF COVARIANCE

The analysis of covariance (ANACOVA) is a statistical procedure which provides a model for the behavior of a continuous dependent variable as a linear function of a set of independent variables, some of which are continuous and some of which are discrete. In this sense it combines the features of both a regression analysis (continuous independent variables) and an analysis of variance (discrete independent variables). The entire problem is handled conditionally on the values of the independent variables so that the only variation assumed is in the dependent variables.

The most natural application of ANACOVA occurs when modeling observations (Y's) which have been taken in the format of one of the usual analysis of variance designs, but other observable variables (X's) are available to the researcher and they are suspected to be contributing significant effects to the magnitudes of the Y's apart from any effects in the analysis of variance portion. Then one ought to add to the model a regression of the Y's on these X's to better explain the variability of the former. The X's are called covariates or concomitant variables. The approach is to adjust the Y's according to the associated X's and only then use the adjusted Y's for analysis and interpretation of the data according to the original analysis of variance design.

An example will clarify the discussion of the previous paragraphs. Suppose we wish to study the braking distance to full stop for different vehicles. We take a set to such observation (Y's). Among the explanatory variables we might consider are:

(a) Brake type - disc, drum, disc/drum (categorical/discrete).
(b) Vehicle speed at time brakes are applied (continuous).
(c) Road surface condition - wet, dry, etc. (categorical/discrete).
(d) Vehicle weight (continuous).
etc.

If, for example, we wish to compare brake types, it is clear that any effects on stopping distance due to differences in brake types will be totally masked by the effect of vehicle speed at the time the brakes are applied. Hence, to run a meaningful test of differences in performance of brake types requires removing the effects of differing vehicle speeds at the time the brakes are applied. In this setting a test of differences among brake types would be handled by an analysis of variance while the differing vehicle speeds would be viewed as values of an independent regression variable. The addition of further discrete variables to this discussion elaborates the analysis of variance portion of the model while the addition of further continuous variables results in additional independent regression variables. However, the basic idea is unaffected. Ultimately, hypothesis tests will be developed for the presence of effects for either type of variable.

The important assumption usually demanded for a valid analysis of covariance is that the concomitant variables are unaffected by (i.e., independent of) the analysis of variance variables. In the above example, for instance, it is reasonable to assume that the vehicle speed at the time the brakes are applied is independent of the type of brake system on the vehicle. Even when such independence may not quite hold, one can still apply an analysis of covariance. However, the interpretation of the results of such an analysis must be carefully considered due to the confounding of variable effects.

We now formally develop the analysis of covariance (ANACOVA). For convenience we assume one categorical (or discrete) variable and one continuous varable and then the model:

$$(1)\quad Y_{ij} = \mu + \alpha_i + \beta(X_{ij} - \bar{X}..) + \varepsilon_{ij}$$

$$j = 1, \ldots, n_i,\ i = 1, \ldots, k$$

with
$$\bar{X}.. = \sum_{i=1}^{k} \sum_{j=1}^{n_i} X_{ij}/n \quad \text{and} \quad n = \sum_{i=1}^{k} n_i$$

In this model we would interpret Y_{ij} as the observed stopping distance of the j^{th} vehicle (or j^{th} stop of one vehicle) having brake type i. X_{ij} is the associated vehicle speed at the time the brakes were applied and is centered about $\bar{X}..$; the overall mean of the X_{ij}'s and ε_{ij} is the model error for the observations. These errors are assumed normally distributed and independent (the latter being quite reasonable in our example). The parameter μ is the overall mean braking effect; α_i is the effect due to brake type i; and β is the regression coefficient for the independent variable, vehicle speed.

Two hypotheses are of interest to test

H_1: $\alpha_1 = \alpha_2 = \ldots\alpha_k = 0$, and

H_2: $\beta = 0$

H_1 tests for the brake effects, i.e., no differences in performance of the different brake types. H_2 tests whether the inclusion of the covariate actually explained a significant amount of the variation in the Y's. Presumably H_2 will be rejected or else we would not be considering the X's in the first place. In our example, certainly vehicle speed at the time the brakes are applied affects the vehicle's stopping distance.

From (1)

$$Y_{ij} - \beta\ (X_{ij} - \bar{X}..)$$

would be exactly the adjusted observation we would want for testing H_1. Unfortunately, since β is unknown, these adjusted Y_{ij} are not "observable." However, if b is an estimate of β we will define

$$Y_{ij} - b\ (X_{ij} - \bar{X}..)$$

as the adjusted value of Y_{ij} (usually said to be adjusted to $\bar{X}..$). This adjustment of the Y observations will change the entire picture of the experiment.

Let us introduce convenient and somewhat "standard" notation for the various sums of squares to be considered.

$$S_{yy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (Y_{ij} - \bar{Y}_{..})^2$$

$$T_{yy} = \sum_{i=1}^{k} n_i (\bar{Y}_{i.} - \bar{Y}_{..})^2$$

$$E_{yy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (Y_{ij} - \bar{Y}_{i.})^2$$

$$S_{xx} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})^2$$

$$T_{xx} = \sum_{i=1}^{k} n_i (\bar{X}_{i.} - \bar{X}_{..})^2$$

$$E_{xx} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})^2$$

$$S_{xy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})(Y_{ij} - \bar{Y}_{..})$$

$$T_{xy} = \sum_{i=1}^{k} n_i (X_{i.} - \bar{X}_{..})(\bar{Y}_{i.} - \bar{Y}_{..})$$

$$E_{xy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})(Y_{ij} - \bar{Y}_{i.})$$

where

$$\bar{X}_{i.} = \sum_{j=1}^{n_i} X_{ij}/n_i \text{ and } \bar{X}_{..} \text{ as before}$$

$$\bar{Y}_{i.} = \sum_{j=1}^{n_i} Y_{ij}/n_i \text{ and } \bar{Y}_{..} = \frac{\sum_{i=1}^{k} n_i \bar{Y}_{i.}}{n} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} Y_{ij}}{n}$$

It is easy to verify that $S_{yy} = T_{yy} + E_{yy}$, $S_{xx} = T_{xx} + E_{xx}$ and $S_{xy} = T_{xy} + E_{xy}$. Computational formulas for these quantities may be easily developed by expansion.

First consider the hypothesis H_2. From (1) we may fit a regression line for each of the n_i observations at a fixed i. The resultant estimators would be

$$b_i = \frac{\sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})(Y_{ij} - \bar{Y}_{i.})}{\sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})^2} \qquad i = 1, \ldots . k$$

Pooling these estimations we obtain:

$$\bar{b} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})(Y_{ij} - \bar{Y}_{i.})}{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})^2} = \frac{E_{xy}}{E_{xx}}$$

$\bar{b}^2 E_{xx}$ is the sum of squares associated with $\bar{b}$ while $E_{yy} - \bar{b}^2 E_{xx}$ is the appropriate error sum of squares. The former has one degree of freedom associated with it while the latter has $n - (k+1) = n-k-1$. Thus, we can test H_2 using:

$$(2) \qquad \frac{\bar{b}^2 E_{xx}}{(E_{yy} - \bar{b}^2 E_{xx}) / (n-k-1)}$$

The statistic (2) is distributed as F with 1 and n-k-1 degrees of freedom and we reject H_2 for large values.

While $\bar{b}$ seems to have arisen in a rather arbitrary manner,one can show that it is, in fact, the least squares estimator of β.

Returning to H_1, under this hypotheses (1) becomes

$$(3) \qquad Y_{ij} = \mu + \beta (X_{ij} - \bar{X}_{..}) + \varepsilon_{ij}$$

The model in (3) is just a simple linear regression for the entire set of n observations. The least squares estimate of β for such a model is

$$\hat{b} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})(Y_{ij} - \bar{Y}_{..})}{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})^2} = \frac{S_{xy}}{S_{xx}}$$

$\hat{b}^2 S_{xx}$ is the sum of squares associated with $\hat{b}$ while $S_{yy} - \hat{b}^2 S_{xx}$ is the error sum of squares for fitting (3). The difference between the error sum of squares of the reduced model (3) and the error sum of squares of the full model (1) is the sum of squares associated with the α_i, i.e., with H_2 and equals

$$(S_{yy} - \hat{b}^2 S_{xx}) - E_{yy} - \bar{b}^2 E_{xx})$$

This sum of squares may be shown to have k-1 degrees of freedom associated with it while as before the error sum of squares for the full model has n-k-1. Thus, we can test H_1 using

$$(4) \qquad \frac{[(S_{yy} - \hat{b}^2\, S_{xx}) - (E_{yy} - \bar{b}^2\, E_{xx})]/(k-1)}{(E_{xx} - \bar{b}^2\, E_{xx})/(n-k-1)}$$

The statistic (4) is distributed as F with k-1 and n-k-1 degrees of freedom and we reject H_1 for large values of F.

In addition to performing the F tests in (2) and (4) it is customary to present a table of adjusted $\bar{Y}_i$'s as an aid in interpretation. The adjusted $\bar{Y}_i$'s are defined as

$$\bar{Y}_i - \bar{b}\,(\bar{X}_{i.} - \bar{X}_{..})$$

In our example the adjusted $\bar{Y}_i$ would be the average stopping distance for vehicle(s) with brake type i adjusted for speed when brakes were applied. These adjusted average stopping distances can be compared directly to assess differences in average performance of the various brake systems.

The reader seeking further detail on the analysis of covariance may consult Bancroft or Snedecor and Cochran for elementary discussions [1,2].

To illustrate the Analysis of Covariance, consider the following fictitious data set.

Vehicle Number	Brake Configuration		Speed at Time Brakes Applied	Stopping Distance
1	Drum	Type 1	30	80 (4.38)*
2	Drum		40	105 (4.65)
3	Drum		50	170 (5.13)
4	Drum		60	240 (5.48)
5	Disc/Drum	Type 2	30	64 (4.16)
6	Disc/Drum		40	92 (4.52)
7	Disc/Drum		60	226 (5.42)
8	Disc	Type 3	30	60 (4.09)
9	Disc		50	140 (4.90)
10	Disc		60	210 (5.35)

---

*Values in parentheses are logarithms of stopping distances, which will be used in the alternative analysis. These values are plotted in Figure B-1.

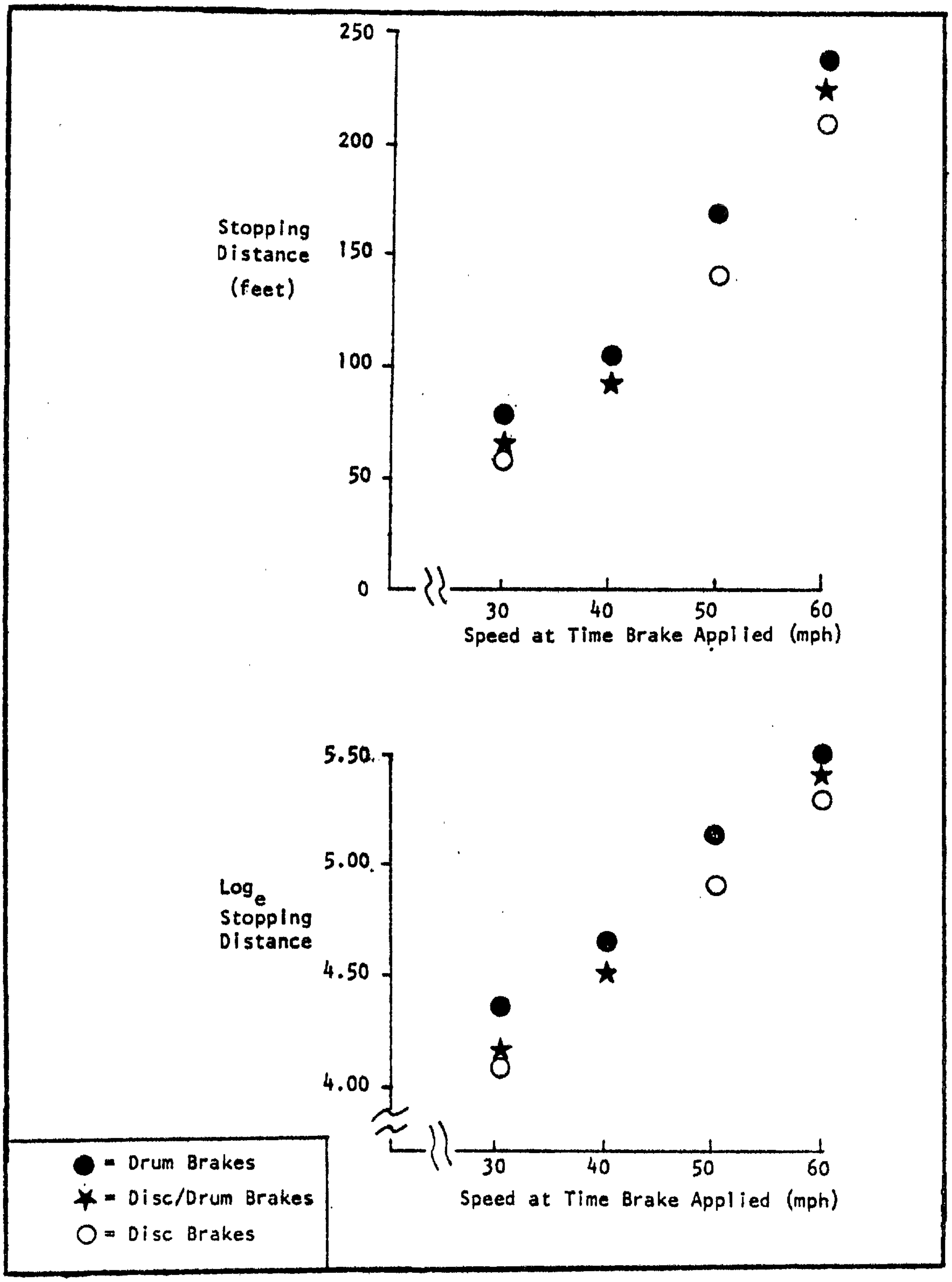

Figure B-1. Plots of fictitious stopping distances.

For this set of data we compute:

$$S_{yy} = 49{,}372.1 \ , \ S_{xx} = 1450 \ , \ S_{xy} = 8095$$

$$E_{yy} = 47{,}830.1 \ , \ E_{xx} = 1433.31 \ , \ E_{xy} = 8048.3$$

$$T_{yy} = 1542.0 \ , \ T_{xx} = 16.7 \ , \ T_{xy} = 46.7$$

Our pooled estimate of β is

$$\hat{\beta} = \frac{E_{yy}}{E_{xx}} = 5.6$$

The associated F statistic for H_o: $\beta = 0$

is $$\frac{(E_{xy}^2/E_{xx})/1}{(E_{yy}-E_{xy}^2/E_{xx})/7} = \frac{45{,}192.4}{376.8} = 119.9$$

which is extremely significant, as would be expected.

To test H_o: $\alpha_1 = \alpha_2 = \alpha_3 = 0$, we compute the associated F statistic

$$\frac{[(S_{yy}-S_{xy}^2/S_{xx}) - (E_{yy}-E_{xy}^2/E_{xx})]/2}{(E_{yy}-E_{xy}^2/E_{xx})/7} = \frac{771.01}{376.80} = 2.05$$

which yields a description level of significance of approximately 0.2 under an F distribution with 2 and 7 d.f. respectively. While this is not terribly significant, it suggests that with more observations the hypothesis may be more decisively rejected.

The adjusted $\bar{Y}_{i.}$'s are

$$\text{adj } \bar{Y}_{1.} = \bar{Y}_{1.} - \hat{\beta}\ (\bar{X}_{1.} - \bar{X}_{..}) = 141.25 - 5.6\ (45\text{-}45) = 141.25$$

$$\text{adj } \bar{Y}_{2.} = \bar{Y}_{2.} - \hat{\beta}\ (\bar{X}_{2.} - \bar{X}_{..}) = 127.33 - 5.6\ (43.33\text{-}45) = 136.67$$

$$\text{adj } \bar{Y}_{3.} = \bar{Y}_{3.} \quad \hat{\beta}\ (\bar{X}_{3.} - \bar{X}_{..}) = 136.67 - 5.6\ (46.67\text{-}45) = 127.33$$

Our variance estimate is $\hat{\sigma}^2 = 276.8$ with $\hat{\sigma} = 19.4$. Thus $\hat{\sigma}_{\text{adj } \bar{Y}_{1.} - \text{adj } \bar{Y}_{2.}}$ $= \hat{\sigma}_{\text{adj } \bar{Y}_{1.} - \text{ adj } Y_{3.}} = 14.7$ and $\hat{\sigma}_{\text{adj } \bar{Y}_{2.} - \text{ adj } \bar{Y}_{3.}} = 15.8$ and we see that the difference in adjusted $\bar{Y}_{i.}$ is within the standard deviation, an insignificant finding.

However, a bit of study of the data indicates that speed at time brakes are applied (X) and stopping distance (Y) are not linearly related but are related approximately exponentially; (this is in fact suggested by numerous studies), i.e.,

$$Y = ae^{bx}$$

Hence, log Y and X would be approximately linearly related. Suppose we redo the analysis of covariance with log stopping distance as the dependent variable. The log stopping distances are given in parenthesis in the last column of the data table.

For this new ANACOVA we have

$$\begin{array}{lll} S_{yy} = 2.47 & S_{xx} = 1450 & S_{xy} = 58.8 \\ E_{yy} = 2.39 & E_{xx} = 143.3 & E_{xy} = 58.33 \\ T_{yy} = 0.08 & T_{xx} = 16.7 & T_{xy} = 0.47 \end{array}$$

This time $\hat{\beta} = 0.041$ and the associated F statistic for $H_o:\beta = 0$ is 1013.2. Again to test H_o: $\alpha_1 = \alpha_3 = 0$, we obtain

$$F = \frac{0.0666/2}{0.0164/7} = 14.2$$

That is, now F is significant at level 0.005. The transformation of the data has drastically improved the fit of the model and dramatically revealed the differences between the brake systems. The differences are also shown by the adjusted log $\bar{Y}_{i.}$ which are:

$$\text{adj log } \bar{Y}_{1.} = 4.91$$

$$\text{adj log } \bar{Y}_{2.} = 4.77$$

$$\text{adj log } \bar{Y}_{3.} = 4.74$$

Again, if we look at $\hat{\sigma}^2 = 0.0023$, we have $\hat{\sigma} = 0.048$. Thus, we have $\hat{\sigma}_{\text{adj log } \bar{Y}_{1.} - \text{adj log } \bar{Y}_{2.}} = \hat{\sigma}_{\text{adj log } \bar{Y}_{1.} - \text{adj log } \bar{Y}_{3.}} = 0.036$ and $\hat{\sigma}_{\text{adj log } \bar{Y}_{2.} - \text{adj log } \bar{Y}_{3.}} = 0.039$. Now the difference in adjusted log $\bar{Y}_{i.}$ can exceed (between 1 and 3) 4 times the standard deviation, a highly significant finding.

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LOGLINEAR MODELS

Most of the classical statistical techniques such as regression analysis, correlation analysis, analysis of variance and their multivariate extensions concern themselves with the problems of finding, describing and assessing the significance of relationships between continuous variables. Analysis of variance (and related techniques) provide methods to assess the variability of a continuous variable on the basis of the presence or absence of discrete variables and so it provides a possible beginning point for the analysis of a discrete dependent variable behavior as a function of discrete independent design variables.

For many years the standard practice when faced with truly categorical or frequency count data was to use analysis of variance even though its use could not be generally supported by theory. However, through the tricks of transforming the original dependent variable, theoretical justification for analysis of variance of discrete data could be argued.

Recently the problem of correctly analyzing discrete data has been put on a solid theoretical footing with the development of loglinear models, which are described by Haberman, and Bishop, Fienberg and Holland [4,1]. Rather than continue to belabor the mathematics of the normal probability distribution that forms the backbone of the linear models involved in regression analysis and analysis of variance, a number of researchers have applied themselves to the development of a body of theory that is specifically designed for the analysis of frequency count data, especially frequency count data that take the form of cross-classified tables of counts.

The essential idea that allows development of such models is replacing most of the normal distribution by the Poisson distribution as a starting point for any theoretical discussion. The Poisson and the related multinomial distribution are the basic sampling distributions used in frequency count data. Just as the normal distribution enjoys the properties of being mathematically tractable, broadly applicable, and theoretically justifiable for continuous data,so too does the Poisson enjoy the same properties for discrete data. By modeling frequency counts as random variables generated by Poisson processes, the problem of analyzing such sets of counts can be couched in terms of the well developed theory of estimation for exponential families of frequency distribution [4,6].

In matrix notation the classical models can be expressed as follows: let $\underset{\sim}{Y}$ be a vector of observed values, let $\underset{\sim}{X}$ be a design matrix, let $\underset{\sim}{\beta}$ be a vector of model parameters, then any of the standard regression and analysis of variance models may be expressed as

$$E(\underset{\sim}{Y}) = \underset{\sim}{X}\underset{\sim}{\beta} \qquad (1)$$

where $E(\cdot)$ is the usual expectation operator. Loglinear models may be expressed similarly by letting $\underset{\sim}{f}$ be a vector of frequencies, $\underset{\sim}{T}$ a design matrix and $\underset{\sim}{c}$ a vector of model parameters, then the loglinear model is given as

$$\ell n\ E(\underset{\sim}{f}) = \underset{\sim}{T}\ \underset{\sim}{c} \qquad (2)$$

where ℓn is the logarithm function.

Once the model, (2), is set up, the problem of estimating the vector of parameters $\underset{\sim}{c}$ must be considered. Concomitantly the problem of estimating the actual predicted values, $E(\underset{\sim}{f})$, must be faced. Fortunately, if one solves either problem, the other is automatically solved.

Various researchers have suggested various techniques to solve the estimation problem. The major schools of thought can be categorized as the maximum likelihood approach [1,4], the minimum discrimination information approach [5] and the weighted least squares approach [3]. All of these approaches are identical asymptotically and, more realistically, they all seem to agree on reasonable size data bases. However, there is no proof that for finite samples they would always "agree." The choice of technique is really a matter of specific application, complexity of analysis desired, and ease of computation. For most loglinear models as applied to cross-classified data, the maximum likelihood approach offers the user an easy algorithm to be employed to compute E(f) under the model and to, therefore, estimate the vector of parameters c. The algorithm is called iterative proportional fitting and dates back to 1940 when it was used to adjust tabled data so that the table's marginal distributions would "agree" with some desired standard distribution [2]. (See the Adjusting Rates section of this appendix for more discussion of the use of the iterative proportional fitting algorithm.) For situations in which more than just "model fitting" is desired, then a generalized Newton-Raphson technique must be used to solve the maximum likelihood equations or one must forego maximum likelihood and turn to one of the other techniques. Newton-Raphson maximum likelihood, weighted least squares and minimum discrimination information techniques all demand the ability to invert large matrices, but they all provide the user with the necessary parameter variance-covariance matrix needed for testing and setting confidence limits. Simply put, the detail of analysis desired is directly related to the computational power to which one must have access.

Regardless of the particular estimation techniques used to fit and test models for categorical data, it is now possible to explore such data from a sound theoretical footing with the use of loglinear analysis.

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CLUSTERING

A cluster is a group of similar objects. As such, clusters are very familiar; indeed, almost all words are cluster labels; car, house, physician, milkshake, green--all conjure in the mind generic objects or qualities. Clusters serve many purposes, of which three major ones are *summarizing, prediction,* and *theory development.*

Clusters summarize because objects are described by properties of the clusters to which they belong. All the details particular to the object and irrelevant to the present purpose are ignored. For example, in response to "What bit the mailman?" the reply, "a dog," or, "an Irish Setter," is better than "Sir Oliver Flaherty,..." where the pedigree has been omitted, even though all those responses describe the same animal.

Clusters predict because we expect objects in the same cluster to be similar, or to share similar properties. When the clusters being examined are sufficiently distinct (and particularly when this is unexpected), there is great incentive to uncover the reasons underlying the clustering. This may lead to new theory, and thus, the third major use of clustering.

The recent formal development of clustering techniques began in the 1950's spurred on by biologists interested in numerical taxonomy. Many of the techniques in use are eminently reasonable, but have as yet no sound statistical basis.* In the introduction to his book, *Exploratory Data Analysis,* Tukey says that it is well to know what you can do before you measure how well you have done it [6].

To the extent that methods of measuring "how well one has done" are still unavailable, clustering remains an art to be practiced with care. The ready availability of computer programs that cluster has probably led to an many unsound and incorrect analyses as the blind use of multiple regression.

Methods of Clustering

Clusters can be grouped as follows:

- Partitions
- Hierarchical clusters
- Clumps

In a partition, an object cannot belong to two clusters simultaneously, and every object is in a cluster. In hierarchical clusters there are different levels of clusters. At each level the objects are partitioned. At the highest level, all the objects are in a single cluster. Lower level clusters are either wholly within or wholly without higher level clusters--the classic example being the classification of animals: a lower cluster being "primates," which is part of "mammals," a subgroup of "vertebrates," etc. The hierarchy is often described by a tree or dendrogram,

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*However, it is reassuring to note that many sturdy babies have parents totally ignorant of genetics and physiology.

with high level clusters as big branches, lower level ones as twigs. The objects clustered would be leaves. Clumps are clusters that can overlap. In later sections, unique assignment of objects to clusters is the main interest and clumping is not considered.

So far, the objects to be clustered have not been clearly defined. In most applications the data are arranged as an array, with cases as rows and variables as columns. Usually the objects to be clustered are cases and the variables are used to determine cluster assignment. After clustering, the average or modal value of a variable in a cluster is the typical value for a case in the cluster. The cases have been reduced to a lesser number of clusters. The variables can be reduced in a similar manner. If linear combinations of variables are considered, the first few principal components or some small number of factors from a factor analysis might be kept. The clusters then correspond to the principal components or factors. There are also techniques that simultaneously cluster both cases and variables.

Some Specific Clustering Techniques

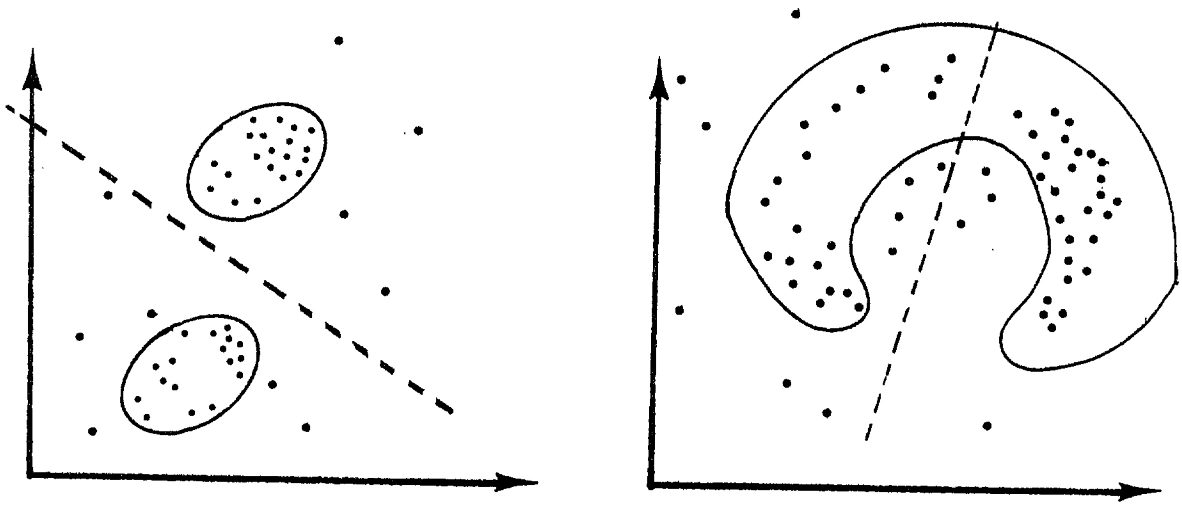
For each method described, the kind of data for which it is appropriate, the nature of the clusters produced and an illustrative example are given. The description of the technique is pared to the motivating rationale; greater detail and complete algorithms can be found elsewhere in the references.

K-means

This technique uses Euclidean distances. The variables used in the distance calculation should be continuous and properly scaled. Given a specific number K of clusters, it allocates objects to clusters so as to minimize the within-cluster sum of squares. The allocation is achieved by iterative swapping of points between clusters, and a version of the algorithm is soon to be available in the BMDP set of statistical computer programs.

The clusters produced by the K-means technique tend to be convex--if the clusters are expected to be snakelike, then K-means is inappropriate, as the "snake" generally will be broken into more than one cluster. See Figure B-2.

When the number of clusters, K, is changed, the new clusters need have no nice relationship to the old ones. Indeed, the question of how many clusters to use is still open, despite recent theoretical developments.



Good Data for K-Means

Bad Data for K-Means

Notes:
For K=2, the clusters are defined by a separating hyperplane.
- - - - = the separating line.

Figure B-2. K-means clustering.

Single Linkage

This method uses Euclidean distances, and it produces hierarchical clusters. Typical objects for which single linkage is a good technique are stars in the sky, and the corresponding clusters are constellations. With this example in mind (see Figure B-3) a clustering is determined by a threshold distance. If, by moving from star to star with jumps less than this threshold, it is possible to move from one star to some other star, then these stars are in the same cluster or constellation. When the threshold distance is increased, early clusters join to form larger ones. Single Linkage clusters are usually long and straggly, and are most unlikely to be convex. As such, they do not correspond to one's intuitive idea of a cluster being a distinct ball in multidimensional space. The fault, if any, lies with intuition, which is but the unusual and incomprehensible tamed by familiarity.

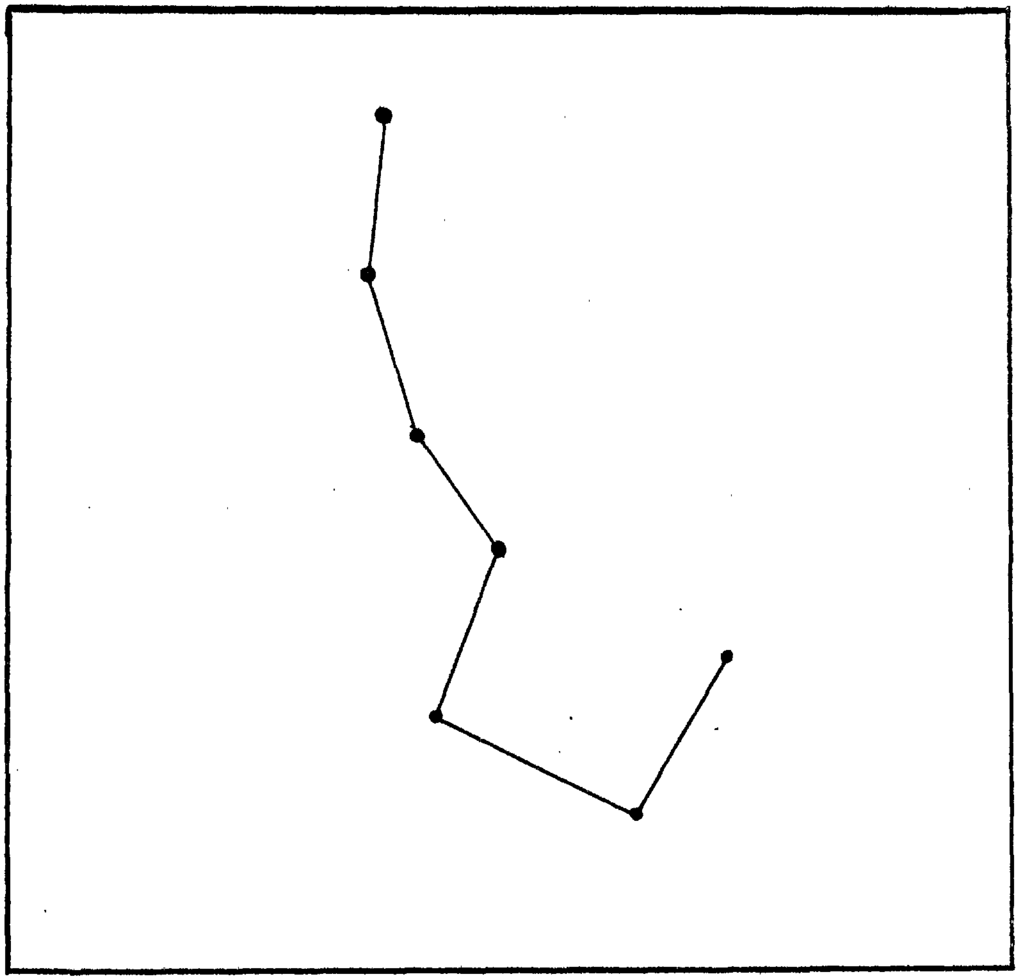


Figure B-3. The constellation Ursa Minor, with its single linkage cluster indicated.

Some Difficulties with Clustering

Almost all clustering algorithms work with distances. Once the clusters have been found, and compelling reasons for their existence unearthed, then good variables that separate the clusters can be defined. However, it is exactly these variables that we need to produce the clusters. This is not the "chicken or the egg" problem exactly, but it does show that the activity of clustering should be iterative: one clusters, then scrutinizes the results, and clusters again.

If variables are measured in different units--say speed in kilometers per hour, lengths in millimeters and distances in meters--they are not immediately comparable. They should be scaled before being used in calculating distances. The usual scaling standardizes using an inverse covariance matrix, to produce Mahalahobis-like distances. When doing this, it is most important to use the within cluster covariance matrices; even if the clusters are real, their positioning may lead to an overall covariance matrix that cannot show the individual clusters distinctly, as shown in Figure B-4.

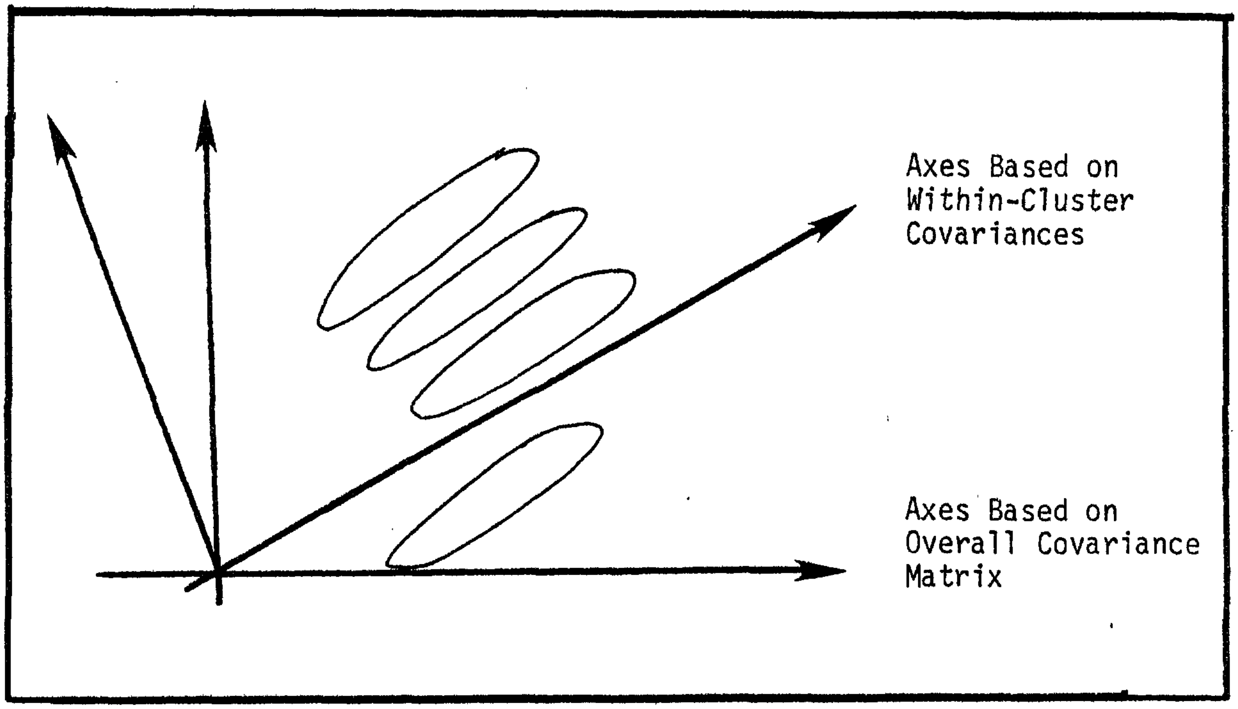


Figure B-4. Scaling with different covariance matrices.

Another question that has to be decided by the practitioner stems from the following: when many highly correlated measurements have been made on each object, the particular attribute measured is given importance corresponding to the number of measurements taken. Taken to extremes, only that attribute will be used in producing clusters. If Euclidean distance is used, this effect can be satisfactorily dealt with by using the principal components, each standarized to have unit variance, since the many essentially repeated measurements will tend to produce one principal component. However, by standardizing to unit variance, those principal components associated with the smallest latent roots, and which therefore correspond to random error in the data matrix, are given the same weight as the components with most of the information. Knowledge of both the clustering technique and the field in which it is applied is important if one is to guard against such possibilities.

The focus of much current research in clustering is how can the reality of clusters be assessed. For most clustering algorithms there is at best very limited theory leading to testable hypotheses. Most cluster validation is performed by running the algorithm on the data several times, omitting cases and/or variables at random. Those clusters that survive best are judged more likely to be actually present in the data. While the statistical theory can be circumvented by such devices, precise understanding of the relative merits of different clustering algorithms will develop only in conjunction with the theory.

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MATCHING

Matching elements from two (or more) populations prior to making inferences about the differences between the populations has a long history in statistical studies. This is primarily due to the fact that matching is such an intuitively reasonable procedure.

Comparing similar elements to assess "treatment effects" rather than comparing, say, the two sampled population means seems like a reasonable procedure to use to reduce extraneous sources of variation that could possibly "mask" the treatment effect itself. Historically, it is this intuitively appealing notion that matching is, in effect, a "self blocking" technique useful for variance reduction that has made matching such a popular technique. Recently, matching has received added status as a straightforward method to reduce sampling costs in expensive experimental situations, e.g., experimental medical trials, surgical techniques or cancer treatment programs. Another recent application has been to apply matching in a *post hoc* fashion so as to "increase one's powers of inference" in non-experimental situations such as survey data.

It is especially the latter application of matching that is germane to the evaluation of FMVSSs using existing data bases, because we are often attempting to compare Pre- *versus* Post-Standard vehicles "free" of extraneous sources of variation. Matching is then very appealing as an easily understood method of variance reduction in observational evaluation studies such as the evaluation of Standards. However, there are definite methodological and even purely practical problems associated with matching. Over the last few years a number of researchers have strongly argued that matching is:

(1) Over-rated as a variance reduction technique.

(2) Expensive to implement, because even reasonably large data bases lose both in creating a large enough potential matching pool and then in searching for matches.

(3) Capable of producing extremely non-representative samples of "matched-pairs" neither member of which adequately reflects its parent population.

(4) Capable of actually masking certain effects related to the matching variables.

(5) Easily replaced by well-understood techniques of analysis of covariance and straightforward blocking, which is the most damaging observation.

Entry to this literature is afforded by the review articles of Cochran and Rubin, and McKinlay [1,2]. A less technical overview that sounds a cautionary note is the more recent article by McKinlay [3].

In conclusion, we do not recommend matching as one of the essential approaches to the analysis of the existing or proposed accident data bases. Our recommendation is based on the simple fact that for such large data bases it is methodologically sounder and more cost effective to use analysis of covariance and/or blocking as the basic approach to "controlled" comparisons of different groups. This is not to say that matching should not be used in the exploratory stages or even when asking specific questions--it should. Like aspirin, matching is not dangerous when used for specific small scale problems and when used in moderation. But is foolhardy when used to the exclusion of other more robust techniques or when used in situations, such as comparisons of large data bases, where it is expensive to implement, wasteful of potential data (the "unmatchables"), and potentially faulty in its implications.

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ADJUSTING TABLES OF COUNTS OR RATES

There are many reasons why a data analyst must sometimes analyze and summarize "adjusted" data rather than original data. Most of the reasons are directly related to the fact that the raw data have certain undesirable properties due to difficulties that have occurred in the data generation and data collection processes.

Some frequently encountered situations and their related reasons for adjustment are:

The Direct and Indirect Methods of Adjusting Rates

These methods address the fact that rates of occurrence in various strata of different populations are not directly comparable if the populations have differing strata structures. This is true since the rates would reflect both differing strata structure and (possibly) population differences of interest to the analyst. It is necessary, therefore, to "hold" structure constant in some sense and only then proceed to make inferences about possible differences between populations. The direct adjustment method approaches the problem by creating a standard population structure and then applying each particular population's rates to this standard population. The result of such a process is a set of expected rates for each population that are comparable in the sense that they are all computed from an agreed-upon standard population structure but reflect individual population rates. The indirect adjustment method approaches the problem by creating a standard set of rates and then applying these standard rates to the number of exposed cases in each cell of the individual population's strata structure. The result is again a set of comparable expected rates for each of the populations. The classic technique used for creating a standard population structure is simply to use the sum of the individual populations; similarly, the classic technique to derive a standard set of rates is simply to sum the occurrences and exposures across population for each strata group. When the standard population or rates are chosen from some outside source, the decision is, of course, highly dependent on the analyst's understanding of the implications that various choices have for his adjustment procedure; in other words, the choice is a matter of subjectively choosing a standard that is appropriate to the particular analytic purpose at hand. A wealth of literature exists which discusses the usefulness and the dangers of such techniques. Entry to it would be provided by the following references: Fleiss (1973), Yerushalmy (1951), Kitagawa (1964), Kalton (1968), Goldman (1971) and Bishop, Fienberg and Holland (1975).

The Adjustment of a Table's Margins to Show "Structure" in the Table and the Adjustment of Different Tables' Margins to Allow Comparisons between Tables.

Often tables of counts are collected so as to allow assessment of association between the variables that define the table structure, e.g., a table of counts of accidents by age and sex of driver would be useful to explore the age-sex association. Of course, we must first define a meaningful and manageable measure of association. A useful reference to the rich field of measures of association is Chapter 11 of Bishop, Fienberg and Holland (1975); however, for our purposes we will focus on the cross-product ratio (for a 2 x 2 table) and on sets of such ratios for multidimensional tables. The essential characteristic of the cross-product ratio that makes it an ideal index of association is that it remains invariant under row and column multiplications by positive constants. Translated into real tables, this means that tables such as below exhibit identical association between factor A and factor B.

$$\left(\frac{2.4}{3.1} = \frac{4.40}{2.30} = \frac{12.20}{90.10} = \text{cross-product ratio}\right).$$

	B	
A	4	3
	1	4

	B	
A	4	30
	2	40

	B	
A	12	90
	1	20

They are simply row and/or column multiples of one another (double the first column and multiply the second by 10 to go from the first to the second table; halve the second row and multiply the first row by 3 to go from the second to the third table). In fact, any table of the form

	B	
A	$2\ r_1c_1$	$3\ r_1c_2$
	$1\ r_2c_1$	$4\ r_2c_2$

exhibits equivalent association between factor A and factor B. With the equivalence of tables under row and column multiplications in hand, we may now approach the problem of displaying association in a table "free of marginal disturbance." A useful approach to the problem of presenting the association in a table to an audience would be to find an equivalent table that has simple margins, such as all marginal totals being 100 or 1, and then use this table to discuss the association structure exhibited by the data. The same idea of "standardizing" the margins is extremely helpful when attempting to look for differences between the structures of two or more tables. By standardizing, the individual cells are directly comparable and similarities and differences stand out free of "masking" caused by marginal differences between the tables. References for the cross-product ratio that are recommended would include Bishop, Fienberg and Holland (1975), especially Chapter 2; Goodman (1964); Mosteller (1968); and Plackett (1973).

The Smoothing of Data to Provide More Precise Estimates of Cell Probabilities

Another problem facing the data analyst interested in the analysis of multidimensional tables is that he often has very small cell counts in a large proportion of his full table. Only by collapsing across variables do reasonable cell counts become available. In these situations (since the faith one can put in any particular estimated cell probability is essentially a direct function of the observed cell count), there are many cell estimates that the analyst feels unsure of. A solution to this problem is to use the lower dimensional "faces" of the multidimensional table to model the full table and thereby provide smoothed estimated cell probabilities with characteristically smaller variances than the raw cell proportions. This technique is the heart of the approach to loglinear model building that Bishop, Fienberg and Holland (1975) present. Their whole approach to loglinear models and, therefore, to adjustment by providing smoothed cell estimates, depends upon the process of marginal standardization just presented in the last section. Namely, lower dimensional observed marginal tables are used as the "standards" while the initial cell entries in the full table are all set to one so that no association (i.e., interaction term) will be preserved other than what exists in the "standard" marginal faces. Of course, other techniques of loglinear model building also provide smoothed estimates with smaller variances too, but they are not so intimately related to the process of marginal standardization. For example, <u>for the mathematically inclined</u>, Haberman (1974), especially pages 376-385, is recommended.

Thus, the reasons for adjustment are: (1) to allow for meaningful interpretation of data and meaningful comparison of separate sets of data; and/or (2) to provide cell estimates in contingency tables that enjoy greater precision than the original data's cell proportions.

Other than the techniques of rate adjustment already mentioned, there is but one underlying technique that must be mastered to accomplish the various "standardization" adjustments and most of the loglinear model building forms of adjustment: namely, iterative proportional fitting (IPF). This iterative technique was suggested by Deming and Stephan (1940) for the adjustment of tables to make margins fit properly; they orginally had no thought of "preserving association under marginal multiplications" but rather suggested IPF as an approximation to a least squares procedure they were proposing.

IPF is easy to remember if one can just focus beyond the acronym to the process of "iteratively proportioning the desired margins among the table's cells until all margins converge on the desired margins." In three dimensions we would begin with some margin, arbitrarily that of variable 1, and adjust every cell in a given layer of the margin by the same multiplicative factor, so that the adjusted layer adds up to the desired marginal total. Next, add up the adjusted marginal totals for variable 2 and adjust each level by multiplying by a factor that makes them add up to the desired variable 2 margin. This, of course, messes up the margin for variable 1, but proceed on to variable 3. Having completed the adjustment so that margin 3 adds up correctly, both margin 1 and margin 2 will be out of kilter. Now simply start the cycle over again with variable 1. The process of iteratively proportioning the margins converges rapidly to a table of all counts with the property that they add to the desired margins.

A simple example using a 2 x 2 table might be valuable:

	2	3	5	1
	1	4	5	1
Actual margin	3	7		
Desired margins	1	1		

→

.4	.6	1.	1
.2	.8	1.	1
.6	1.4		
1	1		

↙

.667	.429	1.096	1
.333	.471	.904	1
1	1		
1	1		

→

.609	.391	1	1
.368	.632	1	1
.977	1.023		
1	1		

→

.623	.382	1.005	1
.377	.618	.995	1
1	1		
1	1		

→

.620	.380	1.	1
.379	.621	1.	1
.999	1.001		
1	1		

STOP

Notice that the process of IPF has in fact left the cross-product ratio unchanged

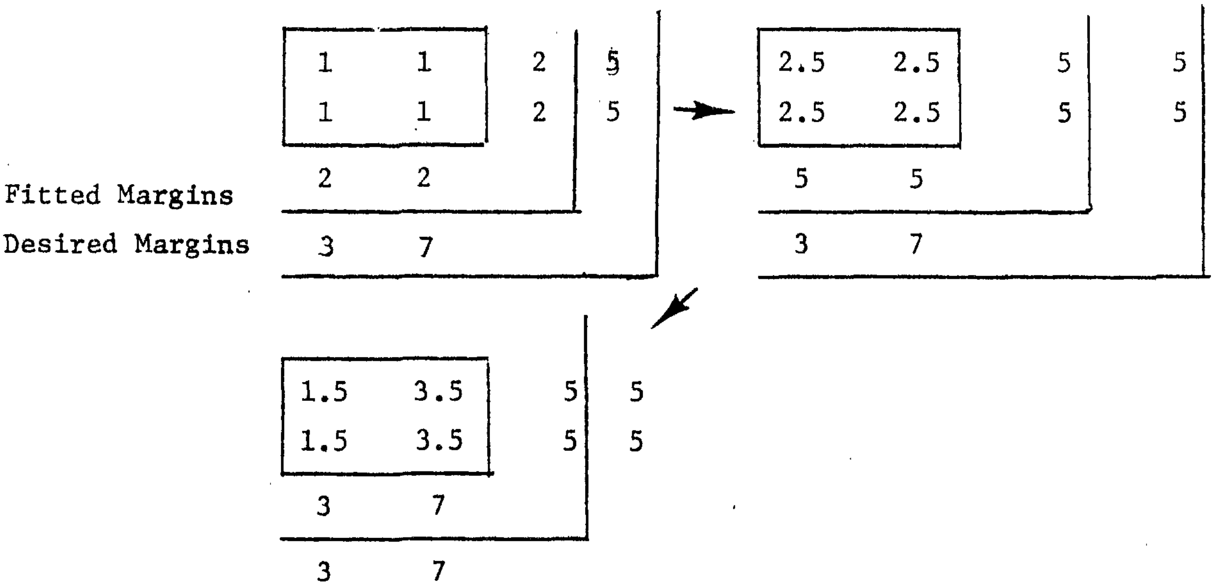
$$\left(\frac{.620 \times .621}{.379 \times .380} \approx \frac{8}{3}\right).$$

IPF is the algorithm that one would use:

(i) To adjust table entries to fit more up-to-date margins such as when margins reflect recent low dimensional data but the table entries are drawn from an older detailed sample. In modeling terms, this situation is using the detailed sample for higher order terms and the low dimensional data for lower order terms.

(ii) To adjust table entries to fit hypothetical margins or some selected set of marginal totals such as all ones (1) or all 100's. This standardization of margins makes it easy to discuss table structure without being bothered by different sample sizes and marginal totals in various layers of the table and, of course, it provides a neat way to allow for immediate comparison of structure between similar tables unencumbered by marginal variation between tables.

Besides these classical uses of IPF to adjust tables, the algorithm can be used to create most loglinear models of interest in the analysis of multidimensional contingency tables. The only new trick involved is to pretend that all one has are the margins and then iteratively proportion them throughout the full table that is initially filled with a constant value in each cell. [It is convenient to pick one (1) as the constant for each cell.] This process yields cell estimates that are identical with those of the loglinear model which has terms corresponding to each of the marginal faces used in the IPF. Actually, there is a technical quibble here in that the use of, say, a two-dimensional margin in IPF is equivalent to having both the corresponding two-factor interaction <u>and both</u> single factor terms in the loglinear model. For detailed information, the reader is urged to refer to Bishop, Fienberg and Holland (1975), and Fienberg (1977) but a simple example would show the basics.



Note that the cross-product ratio is one (1) indicating complete independence or lack of association between factor A and factor B which corresponds to the loglinear model with no two factor interaction term.

The IPF algorithm is also valuable because (a) it provides non-zero cell estimates for cells with sampling zeros (providing that the whole layer is not empty) and (b) it is easily amended to fit very complicated models where certain cells have to have some particular value. The ability to provide non-zero cell estimates is a simple function of the fact that the initial table of ones (1) is used to spread the observed marginal totals through the table. Therefore, empty cells are "proportioned" a share of the marginal information for their row, column, layer, etc. Similarly, the characteristic of being able to fit tables (equivalently, models) with fixed zeroes, fixed diagonals, etc. is accomplished by simply leaving a zero in the initial table for those cells and adjusting the initial margins to "leave room" for whatever fixed value one wishes to have.

In summary, IPF is an easy-to-program algorithm with broad applicability to the various types of adjustment problems we have discussed. It is also the basis for computing the expected cell counts under a wide class of loglinear models and so it ties together the problems of adjustment and the related problems of data smoothing by model building and prediction for multidimensional contingency tables. One should not,however, believe IPF is necessarily the only or even the best answer to loglinear model building and the concomitant process of data smoothing. As an adjustment technique, IPF is a marvelous tool but as a model building and testing device it lacks certain traits. It can not, for example, provide the user with a parameter covariance matrix, so certain hypothesis tests and confidence level statements are precluded. The only solution to this problem is to turn to other techniques for model building and testing. Good references for such techniques would be: Bishop, Fienberg and Holland (1975) - Chapter 10 provides an overview of such techniques; Haberman (1974) - difficult but elegant presentation of the maximum likelihood approach; Grizzle, Starmer and Koch (1969) - the linear models (GENCAT) approach; and Kullback (1971) - the information theoretic approach to loglinear model building.

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APPENDIX C

DISCUSSION OF PROPOSED STANDARD IMPLEMENTATION COST CATEGORIES

NHTSA has stated that to measure the consumer's out-of-pocket expenses,the cost categories should be:

- Direct manufacturing
- Indirect manufacturing
- Capital investment (including testing)
- Manufacturers' markup
- Dealers' markup
- Taxes*

However, we feel that the consumer's initial costs are determined by a complex process, with different types of bargaining at the retail, wholesale,and manufacturing levels. It is well recognized, and also acknowledged by the auto manufacturers, that wholesale prices are set in response to market conditions, and that their relationship to manufacturing cost is loose. In a recent CEM study** this question was examined and no relation was found between annual increases in manufacturers' cost of satisfying FMVSSs as estimated by GAO, and the retail price increases.

Certain cost categories can be well estimated: direct and indirect manufacturing, and capital investment, including testing. These costs represent real resources used. The question of markups is conceptually very difficult, considering the manufacturers' pricing strategies (trying to cover a market spectrum) and the oligopolistic nature of the market. Using average gross profits for the manufacturing markup would be incorrect and misleading. To find the true markup would require a major study examining manufacturers' detailed cost data and pricing practices (internal and external).

The question of dealer markup is somewhat easier to consider conceptually; however, to determine it in practice is complicated by the trade-in of used cars. It appears highly likely that there is no fixed percentage markup on the dealer level, but a more complicated relationship which depends on the value of the new vehicle, the trade-in and other market conditions. Using an average gross profit, or the difference between wholesale and retail prices, would also be inaccurate and misleading.

With regard to the issue of taxes, this cost is not only borne in the form of a sales tax as the fraction of the components cost of the total car, but it is also accumulated at every stage of manufacturing in the form of property, payroll, sales (intermediate) and excise taxes. Income taxes are another cost; however, they are not directly related to the resources used but to the profitability of the manufacturers.

Therefore, based on the above discussion, we consider it beyond the state-of-the-art to estimate the true out-of-pocket cost of new car buyers due to satisfying the FMVSS. Good estimates of the costs of real resources consumed can be made, but these costs apparently are not passed on immediately or directly to the consumer of that model. Other costs (markups and taxes) are conceptually and practically difficult to establish. The most reliable estimate of consumer cost would have to be aggregated over the entire market and a several year period in order to account for changes in market strategy and conditions.

Another point of concern with regard to the collection of data on cost items is the periods of comparison--one model year before the effective date *versus* the model year that the Standard became effective or the next model year. The first point is that manufacturers have made changes to vehicles prior to the effective date of compliance, especially in the case of totally new models. Secondly, there is the learning curve effect in most manufacturing processes which will reduce the effective cost of manufacturing over time. With regard to this second effect, savings would be difficult to estimate, especially as these new components become more integrated into the basic structure of the vehicle. Therefore, using these time periods for comparison may tend to overestimate the cost of the Standard.

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*Personal communication from Warren G. LaHeist, January 1977.

**CEM Report 4194-574, *Program Priority and Limitation Analysis,* December 1976, Contract DOT-HS-5-01225.

with high level clusters as big branches, lower level ones as twigs. The objects clustered would be leaves. Clumps are clusters that can overlap. In later sections, unique assignment of objects to clusters is the main interest and clumping is not considered.

So far, the objects to be clustered have not been clearly defined. In most applications the data are arranged as an array, with cases as rows and variables as columns. Usually the objects to be clustered are cases and the variables are used to determine cluster assignment. After clustering, the average or modal value of a variable in a cluster is the typical value for a case in the cluster. The cases have been reduced to a lesser number of clusters. The variables can be reduced in a similar manner. If linear combinations of variables are considered, the first few principal components or some small number of factors from a factor analysis might be kept. The clusters then correspond to the principal components or factors. There are also techniques that simultaneously cluster both cases and variables.