

*File Copy*

**OCT 03 1973**

28463

Report No. UM-HSRI-HF-73-16

# **INVESTIGATION OF SWITCHING MODES FOR A THREE-BEAM HEADLAMP SYSTEM**

**Rudolf G. Mortimer  
David V. Post**

*Highway Safety Research Institute  
University of Michigan  
Ann Arbor, Michigan 48105*

June 4, 1973

Contract UM 7204-C128  
Motor Vehicle Manufacturers Association  
320 New Center Building  
Detroit, Michigan 48202

The contents of this report reflect the views of the Highway Safety Research Institute, which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Motor Vehicle Manufacturers Association.

1. Report No. UM-HSRI-HF-73-16	2. Government Accession No. DB 224-468 <del>1115</del>	3. Recipient's Catalog No.	
4. Title and Subtitle INVESTIGATION OF SWITCHING MODES FOR A THREE-BEAM HEADLAMP SYSTEM		5. Report Date JUNE 4, 1973	6. Performing Organization Code
7. Author(s) Rudolf G. Mortimer and David V. Post		8. Performing Organization Report No. UM-HSRI-HF-73-16	
9. Performing Organization Name and Address HIGHWAY SAFETY RESEARCH INSTITUTE UNIVERSITY OF MICHIGAN HURON PARKWAY & BAXTER ROAD ANN ARBOR, MICHIGAN 48105		10. Work Unit No.	11. Contract or Grant No. UM 7204-C128
12. Sponsoring Agency Name and Address MOTOR VEHICLE MANUFACTURERS ASSOCIATION 320 NEW CENTER BUILDING DETROIT, MICHIGAN 48202		13. Type of Report and Period Covered	
15. Supplementary Notes		14. Sponsoring Agency Code	
<p>16. Abstract</p> <p>The objective of the study was to obtain information which is basic to the development of three-beam headlamp switching methods.</p> <p>The conditions in which drivers used each of the beams while driving a car equipped with a three-beam headlamp system, and the sequences of switching between the beams, were measured. Questionnaires were also used to provide information of differences between two- and three-beam system beam usage, and ratings of glare and visibility. A set of statements of human factors control-display design principles were compiled to devise a rating scale for the preliminary evaluation of switching concepts.</p> <p>It is concluded that drivers consider the mid beam to offer a worthwhile increase in visibility, compared to the low beam, and would use it in many night driving conditions.</p>			
17. Key Words THREE-BEAM HEADLAMP SYSTEMS HEADLAMP CONTROL SWITCHES		18. Distribution Statement  UNLIMITED	
19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages 61	22. Price \$5.25



## ABSTRACT

The objective of the study was to obtain information which is basic to the development of three-beam headlamp switching methods.

The conditions in which drivers used each of the beams while driving a car equipped with a three-beam headlamp system, and the sequences of switching between the beams, were measured. Questionnaires were also used to provide information of differences between two- and three-beam system beam usage, and ratings of glare and visibility. A set of statements of human factors control-display design principles were compiled to devise a rating scale for the preliminary evaluation of switching concepts.

Results showed that drivers used the mid beam as the major driving beam on rural two-lane and divided highways, where they now tend to use the low beam, with most switching between the mid and high beams. Low beam is used almost exclusively on urban streets with momentary, occasional use of high beam. Thus, a switching system must be capable of allowing quick switching between mid and high beam, and low and high beam (the latter for compatibility and other reasons); or between all three beams. Application of the rating scale on thirteen three-beam switching concepts showed that the scale discriminates between switching systems. Among the switching systems evaluated, those that were most effective employed hand-operated push-button switches, a three-position lever mounted on the steering column, and a combination of a two-position foot switch and column lever.

It is concluded that drivers consider the mid beam to offer a worthwhile increase in visibility, compared to the low beam, and would use it in many night driving conditions. Proper use of the mid beam is expected to be related to the ease with which drivers can operate the three-beam switching system. Effective

three-beam switching modes consist of (1) those that allow any one of the three beams to be selected with a single motion, or (2) in which an intermediate switch is used by the driver to choose which pair of beams (low/high or mid/high) is available, one of which is selected by a single motion of another switch. Further study is needed to determine which of these modes is understood and used most correctly and easily by drivers, and which they find to be compatible when driving vehicles equipped with two- or three-beam headlamp systems.

The switching sequences recommended in this study and the rating scale provided can be used to develop potentially effective three-beam switching methods, for final evaluation of hardware in driver tests.

## TABLE OF CONTENTS

List of Tables	
List of Figures	
Introduction. . . . .	1
Method. . . . .	3
Phase I: Driving Study of Three-Beam Headlamp Switching .	4
Three-Beam Headlamp Usage Experiment. . . . .	4
Subjects . . . . .	4
The Test Car . . . . .	5
Procedure. . . . .	5
Results . . . . .	11
Beam Usage Questionnaire . . . . .	11
Driving Test: The Sequence of Selection of Beams. . . . .	12
Driving Test: The Use of the Beams. . . . .	18
Ratings of Effectiveness of Beams. . . . .	19
Subjective Comments on Preferred Switching Modes. . . . .	22
Discussion of Phase I Studies . . . . .	22
Phase II: Evaluation of Three-Beam Switching Configurations . . . . .	26
Current Practice in Beam Switching. . . . .	26
Some Examples of Three-Beam Switching Concepts .	29
Evaluation of Switching Concepts by Design Criteria .	31
Development of Evaluation Criteria . . . . .	32
Using the Evaluation Scale . . . . .	39
Discussion of Phase II Evaluations. . . . .	39
Recommendations and Conclusions . . . . .	42
References . . . . .	45
Appendix 1: Instructions for the Driving Test. . . . .	46
Appendix 2: The Three-Beam Switching Configurations Evaluated by the Rating Scale. . . . .	48

LIST OF TABLES

<u>Table Number</u>	<u>Page</u>
1. Two-Beam Usage Questionnaire . . . . .	7
2. Three-Beam Usage Questionnaire - Form A. . . . .	9
3. Three-Beam Usage Questionnaire - Form B. . . . .	13
4. Beam Selection Sequences by Event Using the Three- Beam Headlighting System. Data for 10 Drivers: While Entering, Exiting from and Driving on Freeways.	15
5. Beam Selection Sequences by Event Using the Three- Beam Headlighting System on Rural Roads. Data for 10 Drivers . . . . .	16
6. Beam Selection Sequence by Event Using the Three- Beam Headlighting System on Urban Roads. Data for 10 Drivers . . . . .	17
7. Effectiveness Ratings of a Conventional Two-Beam Headlamp System . . . . .	20
8. Effectiveness Ratings of a Three-Beam Headlamp System . . . . .	21
9a. Primary Statements of Switch Preference of 10 Drivers.. . . . .	23
9b. Summary of Preferences Among Three Beam Switching Systems . . . . .	24
10. Design Concepts of Essential Importance . . . . .	34
11. Design Concepts of Primary Importance . . . . .	35
12. Design Concepts of Secondary Importance . . . . .	37
13. Design Concepts of Tertiary Importance. . . . .	38
14. Evaluation of Three-Beam Headlamp Switching Con- figurations Using Design Concepts as Rating Criteria.	40
15. Frequency of Acceptable Human Factors Design Charac- teristics Met by Each Switching Configuration and Sum of Weighted Subscales in Percent. . . . .	41



LIST OF FIGURES

<u>Figure Number</u>		<u>Page</u>
1.	The test car with three-beam system. The outboard lamps are low/high beam no. 6014 lamps, the inboard lamp on the driver's side is used with the low beam to form the mid beam, and the high beam lamp is on the passenger's side. . . . .	6
2.	Aim of the type III ("mid" beam) lamp . . . . .	6
3.	Three-beam switching configuration A. . . . .	49
4.	Three-beam switching configuration B. . . . .	49
5.	Three-beam switching configuration C. . . . .	50
6.	Three-beam switching configuration D. . . . .	50
7.	Three-beam switching configuration E. . . . .	51
8.	Three-beam switching configuration F. . . . .	51
9.	Three-beam switching configuration G. . . . .	52
10.	Three-beam switching configuration H. . . . .	52
11.	Three-beam switching configuration I. . . . .	53
12.	Three-beam switching configuration J. . . . .	53
13.	Three-beam switching configuration K. . . . .	54
14.	Three-beam switching configuration L. . . . .	54
15.	Three-beam switching configuration M. . . . .	55

## ACKNOWLEDGEMENTS

This study was completed as a part of a research program in vehicle headlighting performance sponsored by the Motor Vehicle Manufacturers Association.

This report is issued under the general contract title: "Passenger Car and Truck Lighting Research: Headlighting Phase 2, Headlight Aim, Beam Selection and Beam Switching."

During the conduct of this study periodic meetings were held with the MVMA Lighting Committee, Headlighting Research Task Force, consisting of Mr. G. Gardner, and Mr. R. Rossio, Charmen; Mr. P. Lawrenz; Mr. P. Maurer; and Mr. B. Preston. The formal and informal discussions with members of the Task Force were helpful and we are pleased to acknowledge their contribution to the research.

## INTRODUCTION

At the present time U.S. vehicles are equipped with a headlighting system consisting of a low and a high beam. The purpose of these two beams is probably reasonably well understood by the majority of the driving population. In order to activate the headlighting system the driver makes use of two switches. In most vehicles there is a dash-mounted push/pull switch with two detented positions, the first corresponding to the parking light position and the second to the headlight position. With the headlamps activated the driver selects between the low and high beam options by depressing a foot-operated switch, usually located at the left lower edge of the firewall. Successive depression of the foot switch alternately selects between these two beams. European and Japanese practice has been somewhat different, both for activating the headlights and for beam switching. For example, it is common to find hand-operated control stalks for beam selection that move in a horizontal plane, such as when they form part of the turn signal switch; or consist of a rotary switch at the end of a stalk mounted at the side of the steering column. By comparison with foreign practice, that used in the U.S. is much more uniform across vehicles, although quite recently a column-mounted switch has begun to be used.

There are numerous considerations affecting the placement and mode of operation of a headlight activating and beam selecting switch. Some of these considerations have already been outlined in previous analyses of vehicle controls and displays (Woodson et al., 1970) and include factors such as: easily identified mode of operation, distinguishability from other controls, positioned so as to reduce inadvertent extinction of the headlights, ease of beam selection, ease of identifiability of beam selected and beam status, operable in emergencies, etc.

It is clear that not all of these properties are adequately met by some current designs.

The problems associated with providing a suitable switching method are complicated when an additional beam is contemplated for introduction. The results of field tests (Hull et al., 1971) and computer simulations (Mortimer and Becker, 1973) have suggested that a mid beam may provide 10%-30% increase in visibility distance compared to the presently used low beam. The mid beam would be particularly suitable for use on divided highways, but could also be used under favorable driving conditions on two-lane rural roads. In order to obtain any benefits that such a beam may provide, it will be necessary that drivers are able to select it appropriately for use in relevant driving conditions. Thus, it will be important that drivers fully understand the operation of a three-beam system in terms of the environmental conditions when it can be safely used to advantage, and are able to comprehend the switching system by which the beams are selected.

This study was concerned with the latter problem. A number of approaches could have been used in the present investigation, such as the direct evaluation of driver performance using three-beam switching systems as a means to attempt to evaluate those that are readily comprehended by drivers and which they operate appropriately. Such an approach was used by Krumm et al. (1972), who carried out a preliminary evaluation of four switching concepts using response time and errors as measures of performance in selecting beams on command, while the subjects were carrying out a tracking task requiring movement of a steering wheel. They found that a dashboard-mounted panel rocker switch required significantly more time to select one of the three beams than either a steering wheel spoke button or horizontally activated turn signal switch control. The frequency of errors in correctly

selecting the beams were not significantly different for the four switching concepts. The study showed, therefore, that differences in the time required to select one of three beams depends upon the specific switching concept employed. However, these data in themselves cannot be reasonably used to determine switching performance guidelines for a three-beam system. The reason for this is that many other concepts could be devised which may appear effective, and hence would require evaluation. Since there are a large number of such alternative concepts, it follows that the evaluation program would be extremely extensive and costly. For these reasons, a different approach was adopted in this investigation.

The basic objective was to derive fundamental guidelines for the design of a three-beam switching system. The procedure consisted of an experimental phase and a human factors analysis. Drivers obtained on-the-road experience with a three-beam system. It appeared reasonable that a study should first be made to determine if drivers will utilize the options available to them in a three-beam system, and the conditions prevailing when each beam is used. Secondly, that study showed the sequences in which the beams are selected, which is also considered to be directly relevant to deriving guidelines for the mode of operation of a three-beam headlamp switching system. These data were then combined with the procedure developed for the evaluation of beam switching concepts to derive guidelines for switching performance.

#### METHOD

Six specific tasks were completed in this study, and are summarized below:

1. A listing of normal and critical incidents involving visibility was formulated, and used to develop a questionnaire to assess the manner in which drivers used headlamp beams.

2. The questionnaire was used to indicate how drivers respond to these incidents with the present two-beam system.

3. A driving experience was provided by building a three-beam system which approximates the future design of such a system, and having drivers use this system in several different road environments while their beam use and selection sequences were measured.

4. These same persons then completed the beam usage questionnaire, to show how they thought they would respond in normal and critical incidents with a three-beam headlamp system, like the one they used in the foregoing task.

5. Based on human factors design principles and the results of importance weightings made by experts, a procedure for the evaluation of beam switching concepts was developed.

6. Characteristics of potentially suitable three-beam switching concepts were defined based on the foregoing evaluations.

#### PHASE I: DRIVING STUDY OF THREE-BEAM HEADLAMP SWITCHING

THREE-BEAM HEADLAMP USAGE EXPERIMENT. A study of beam usage was conducted using a vehicle equipped with three beams. All beam switching was done manually by an experimenter in the rear seat. The instructions for the subjects, shown in Appendix 1, asked them to verbally request any beam, which the experimenter then switched on. Three roadway sections were used. These consisted of rural freeways, including entrance and exit ramps; rural two-lane roads; and urban streets in Ann Arbor. All tests were made between 6:00 p.m. and midnight on weekday nights, during winter months in Michigan.

Subjects. Five male and five female drivers were used as test subjects. They were 21-42 years of age, 57.5-73.0 inches in standing height, and had various vocations. None of them

were lighting experts.

The Test Car. A vehicle was equipped with three beams (Figure 1). The low beam was provided by a pair of 6014 lamps aimed to standard mechanical aim specifications. The mid beam added a "type III" lamp of 50,000 candelas to the low beams. The mid beam was aimed as shown in Figure 2, with the left edge and the upper edge of the high intensity zone approximately  $0.5^\circ$  down and  $1.6^\circ$  left of the H-V axis. The high beam was composed of the 6014 lamps on high beam and the type III plus a type IV lamp. This type IV lamp has an output of about 100,000 candelas and was aimed about  $0.5^\circ$  down and symmetrically about the vertical axis.

Procedure.

1. Two questionnaires, concerned with the way drivers use the beams, were compiled by considering the major situational factors that may influence the selection of a headlamp beam while driving at night. One questionnaire was appropriate for determining beam selection when driving with a two-beam system (Table 1), and the other, quite similar one was used to assess how the beams would be used with a three-beam system (Table 2).

2. Each subject first filled out the two-beam usage questionnaire. This form was used to derive the subject's normal beam usage in common night driving situations.

3. The subject was read the instructions for the test (Appendix 1) and then sat in his own vehicle on a section of straight road while the experimenter drove past him in the test car at 15 mph from about 300 feet away with low beam, mid beam and then high beam on successive runs. The subject was informed as to which beam was in use on each pass.

The subject then drove about five miles on a two-lane rural road while the three beams were presented in a variable fashion



Figure 1. The test car with three-beam system. The out-board lamps are low/high beam no. 6014 lamps, the inboard lamp on the driver's side is used with the low beam to form the mid beam, and the high beam lamp is on the passenger's side.

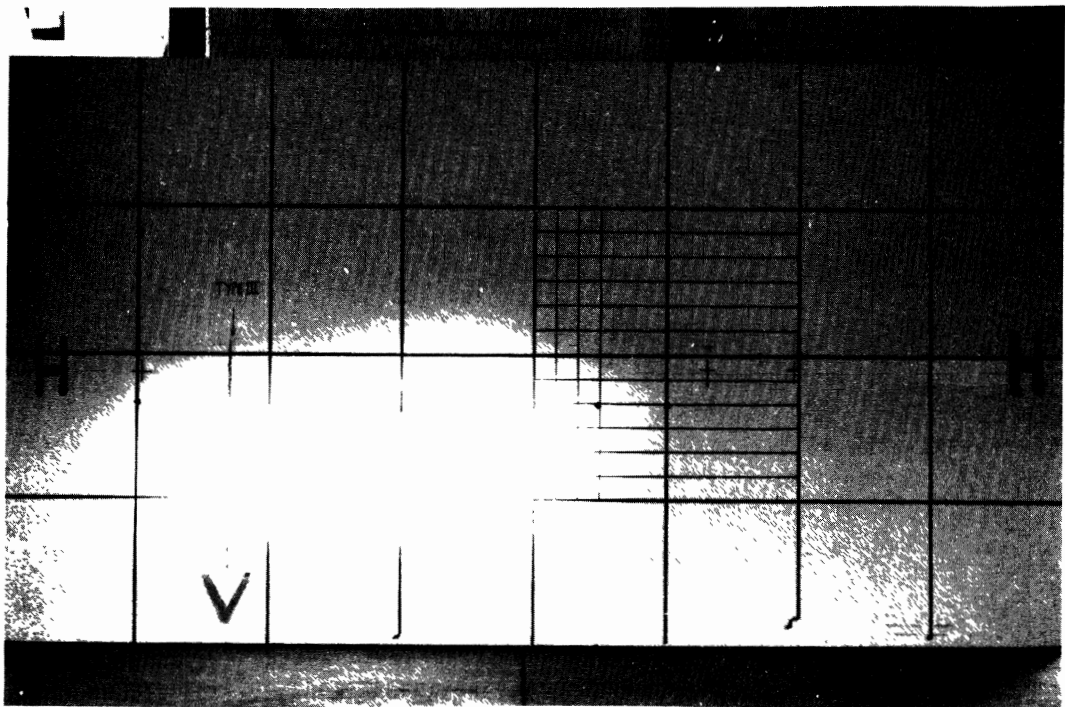


Figure 2. Aim of the type III ("mid" beam) lamp.



TABLE 1. Two-Beam Usage Questionnaire (cont.)

Please describe your use of automotive vehicle forward lighting beams and lamps by putting the appropriate letter in front of the driving conditions listed.

- O where you leave your lights OFF.
- P where you use your PARKING lamps.
- L where you use your LOW beams.
- H where you use your HIGH beams.
- F where you use your FOG beams.
- E where you use your EMERGENCY hazard flashers.

Night driving on city (urban area) streets.

Response  
Maj. Minority

9L	1H	-	1. When traffic is sparse.
10L	-	-	2. When you are behind someone.
10L	-	-	3. When oncoming vehicles approach.
9H	-	-	4. When signaling oncoming drivers on the wrong beam.
4H	1.0	1L	5. When signaling following drivers on the wrong beam.

Night driving on country (rural area) roads.

9.5H	.5L	-	6. When traffic is sparse.
10L	-	-	7. When you are behind someone.
10L	-	-	8. When oncoming vehicles approach.
8H	2L		9. When signaling oncoming drivers on the wrong beam.
3L	2H	1.0	10. When signaling following drivers on the wrong beam.

Note - Totals less than 10 indicate that some subjects do not respond by changing beams in the particular situation.

- One-half units indicate that a driver split his beam usage between two beams.

TABLE 1. Two-Beam Usage Questionnaire (concl.)

Night driving on city (urban area) expressways.

8L	2H	-	11. When you are on an entrance ramp.
5L	5H	-	12. When traffic is sparse.
10L	-	-	13. When you are behind someone.
10L	-	-	14. When oncoming vehicles approach.
8H	-	-	15. When signaling oncoming drivers on the wrong beam.
4H	1.0	1L	16. When signaling following drivers on the wrong beam.
6L	4H	-	17. When you are on an exit ramp.

Night driving on country (rural area) expressways.

6H	4L	-	18. When you are on an entrance ramp.
8.5H	1.5L		19. When traffic is sparse.
9L	1H		20. When you are behind someone.
10L	-	-	21. When oncoming vehicles approach.
8H	-	-	22. When signaling oncoming drivers on the wrong beam.
4H	10	1L	23. When signaling following drivers on the wrong beam.
8H	2L	-	24. When you are on an exit ramp.

Night driving during these conditions.

7.5L	2H	1.5F	25. Rainfall.
8.5L	1.5F	-	26. Fog.
8.5L	1H	.5F	27. Snowfall.

Day driving during these conditions.

8.5L	1.50	-	28. Rainfall.
8L	2F	-	29. Fog.
8.5L	.5F	-	30. Snowfall.
5L	50	-	31. Cloudy (gray skies).
10L	-	-	32. Dusk or dawn twilight period.

TABLE 2. Three-Beam Usage Questionnaire - Form A (cont.)

Please describe your use of automotive vehicle forward lighting beams and lamps by putting the appropriate letter in front of the driving conditions listed.

- O where you leave your lights OFF.
- P where you use your PARKING lamps.
- L where you use your LOW beams.
- H where you use your HIGH beams.
- F where you use your FOG beams.
- E where you use your EMERGENCY hazard flashers.
- M where you would use your MIDDLE beam.

Night driving on city (urban area) streets.

Response  
Maj. Minority

8M	2L	-	1. When traffic is sparse.
5M	5L	-	2. When you are behind someone.
6M	4L	-	3. When oncoming vehicles approach.
7H	2M	-	4. When signaling oncoming drivers on the wrong beam.
5H	1M	-	5. When signaling following drivers on the wrong beam.

Night driving on country (rural area) roads.

8H	2M	-	6. When traffic is sparse.
10M	-	-	7. When you are behind someone.
10M	-	-	8. When oncoming vehicles approach.
9H	-	-	9. When signaling oncoming drivers on the wrong beam.
4H	2M	10	10. When signaling following drivers on the wrong beam.

Note - Totals less than 10 indicate that some subjects do not respond by changing beams in the particular situation.

- One-half units indicate that a driver split his beam usage between two beams.

TABLE 2. Three-Beam Usage Questionnaire - Form A (concl.)

Night driving on city (urban area) expressways.

8M	2H	-	11. When you are on an entrance ramp.
8M	2H	-	12. When traffic is sparse.
9M	1L	-	13. When you are behind someone.
9M	1L	-	14. When oncoming vehicles approach.
9H	-	-	15. When signaling oncoming drivers on the wrong beam.
4H	1M	-	16. When signaling following drivers on the wrong beam.
6M	4H	-	17. When you are on an exit ramp.

Night driving on country (rural area) expressways.

5.5H	4.5M	-	18. When you are on an entrance ramp.
6.5H	3.5M	-	19. When traffic is sparse.
10M	-	-	20. When you are behind someone.
10M	-	-	21. When oncoming vehicles approach.
8.5H	.5	-	22. When signaling oncoming drivers on the wrong beam.
4H	1M	10	23. When signaling following drivers on the wrong beam.
6H	4M	-	24. When you are on an exit ramp.

Night driving during these conditions.

9M	-	-	25. Rainfall.
5M	3L	2F	26. Fog.
8M	1L	-	27. Snowfall.

Day driving during these conditions.

6L	1.5M	1.5O	28. Rainfall.
7.5L	1.5F	1M	29. Fog.
7L	1.5M	1.5O	30. Snowfall.
6L	3O	1M	31. Cloudy (gray skies).
7L	3M	-	32. Dusk or dawn twilight period.

to demonstrate the reaction of oncoming vehicles and the visibility that the beams provided on straight and curved roads, in both opposed and unopposed conditions. After this exposure to the three-beam system the subject was instructed to enter a freeway from an urban road and to continue until directed to exit. The roadway sections were used in the following sequence: freeway-rural-freeway-urban-freeway, or in the opposite order.

4. Upon completion of the course the subject filled out the three-beam usage questionnaire in which the subject described how he would use a headlighting system that included a mid beam.

5. An interview was then taped of comments relating to the experiment and the subject's opinions of beam switching and display devices and their locations. As a part of this discussion three specific switching concepts were explained to the subject and his reaction to them obtained. These concepts included a three-position, pressure-actuated foot switch; a dash-mounted push/pull switch for choosing between a pair of beams which are selected by a foot switch; and a three-position, horizontally-actuated column lever.

#### RESULTS.

Beam Usage Questionnaire. The results of asking subjects to complete the two-beam usage questionnaire, which was used to provide an indication of the manner in which they used a conventional headlighting system, are shown in Table 1. This shows that in driving on city streets most drivers will utilize the low beam, other than for signal purposes to other drivers to indicate they are on the wrong, presumably, high beam. On rural two-lane roads the drivers indicated that they would use high beam when traffic was sparse but in other situations relied on the low beam. On city expressways they mostly reported use of the low beam, other than for signaling purposes. When driving on rural

expressways drivers indicated they would use high beams mostly on entrance and exit ramps, or when traffic was sparse, but in other conditions would be using the low beam. During night driving in rain, fog or snowfall, they would be largely using the low beam; and in daytime under similar weather conditions would use the low beam almost exclusively.

By comparison, Table 2 shows their responses to these questions after they have had an exposure in driving the test car, equipped with a three-beam system. The major effect of this exposure was to shift from use of the low beam in many conditions to the mid beam mode. For example, on city streets the mid beam mode was shared about equally with the low beam mode, other than for signaling purposes to other drivers. On rural roads, city expressways, and rural expressways there was an almost complete shift from use of the low beam, in a two-beam system (Table 1), to the mid beam mode as shown in Table 2. The subjects also felt that the mid beam was suitable in rain and snow conditions, but would share use of the mid beam and low beam under fog conditions. In day driving conditions they would generally continue to use the low beam.

Table 3 shows the responses of the subjects to some additional questions asked in order to provide a further evaluation of the mid beam, after they had driven with it. This indicates that they did not feel that the mid beam caused excessive glare to oncoming drivers, or to preceding drivers. They felt that the mid beam offered a considerable improvement in visibility over the low beam, and that it would be a worthwhile improvement in the vehicle headlighting system. In general, they did not feel that the mid beam could be used to replace the low beam, because the low beam was valuable for driving on city streets and in fog or snow conditions.

Driving Test: The Sequence of Selection of Beams. During the driving test, whenever the subject called for a change in

TABLE 3. Three-Beam Usage Questionnaire - Form B

1. Do you think the mid beam caused glare for oncoming drivers?  
7=No            1=Same as low beam  
2=Some
2. Do you think the mid beam caused glare for preceding drivers?  
8=No  
2=Only in close traffic
3. Do you think the mid beam offers much improvement over the low beam?  
9=Yes  
1=Illumination improved but not visibility distance
4. Do you feel that a mid beam like this would be a significant improvement of your vehicle's headlighting system?  
10=Yes
5. Do you feel that there were any conditions where the low beam was necessary or do you feel the low beam could be eliminated as long as the mid and high beams were available?  
7=Retain low beam for city driving, fog, and snow.  
2=Eliminate low beam.  
1=Eliminate low beam if mid beam can be used successfully in inclement weather.

the beam desired, the associated conditions, shown as events in Tables 4-6, were also noted. Table 4 shows the sequences in which beams were selected while entering, exiting from and driving on rural freeways. Since the vehicle was equipped with three beams, there are six possible sequences in which the beams may be switched. The two lowermost rows in the table show the total frequency and percent, respectively, with which each of the possible sequences was used. It will be noted that 38.7% of the selections were from mid to high and 35.6% from high to mid, for a total of 74.2% of the selections being made between the mid and high beams. Most of the changes from mid to high beam occurred during the approach to an exit ramp with some also occurring on curves, mostly in the left-hand direction. Most of the switching from the high to mid beam occurred when there was another vehicle approaching, during merging maneuvers, at the approach to exit ramps and at the end of a ramp. Switching from low to mid beam occurred mainly at entrance ramps.

Thus, most of the switching was due to changing from the low beam to the mid beam as the freeway was being entered, and with switching between the mid and high beam modes which occurred almost exclusively while on the freeway or while exiting from it.

Table 5 shows similar data for the exposure of the drivers on two-lane rural roads. It will again be noted that most switching (88.5%) took place between the mid and high beams. Switching from mid beam to low beam occurred as road sections containing fixed illumination were encountered. It will be noted that most of the meetings with oncoming traffic occurred with the test car using the mid beam mode.

In Table 6 are shown the sequences in which beams were selected on urban roads and streets. This indicates that the majority of them involved switching between mid and low beams.



TABLE 4. Beam Selection Sequences by Event Using the Three-Beam Headlighting System. Data for 10 Drivers: While Entering, Exiting from and Driving on Freeways.

Event	Beam Changes						Total Row Frequency	Total Row Percent
	L→M	L→H	M→L	M→H	H→L	H→M		
Vehicle coming over hill								
Vehicle oncoming					1	6	7	6.9
Vehicle flashes beams						1	1	1.0
Oncoming vehicle passed		1		2			3	3.0
Vehicle ahead			1			3	4	4.0
Vehicle behind								
Curve	1L		1L	6L 1R			8L 1I	8.9
To signal improper lights or passing				2Ps			2Ps	2.0
Subject passing						2	2	2.0
No traffic				7			7	6.9
Start or change roads								
Street lights								
No or dim streetlights								
Fog or snowfall	3		3	1			7	6.9
To reduce glare						1	1	1.0
Momentary, no apparent cause								
No apparent cause						2	2	2.0
Prompted by experimenter	1		1				2	2.0
Straight no event			1				1	1.0
To see pedestrian/vehicle/object/sign				1V			1V	1.0
Passed pedestrian/vehicle/object/sign								
Approach entrance	2			6		1	9	8.9
Entrance ramp	5			1		1	7	6.9
Merge	2			1		8	11	10.0
Approach exit ramp	2			10		5	17	16.9
Exit ramp				1			1	1.0
End of ramp			1			6	7	6.9
Total column frequency	16	1	8	39	1	36	101	100.0
Total column percent	15.8	1.0	7.9	38.7	1.0	35.6	100.0	

Note - L=Left, R=Right, P=Pedestrian, V=Vehicle, O=Object, S=Sign, Ps=Passing, Lt=Lights.

TABLE 5. Beam Selection Sequences by Event Using the Three-Beam Headlighting System on Rural Roads. Data for 10 Drivers.

Event	Beam Changes						Total Row Frequency	Total Row Percent
	L→M	L→H	M→L	M→H	H→L	H→M		
Vehicle coming over hill						3	3	2.7
Vehicle oncoming						44	44	38.9
Vehicle flashes beams				1			1	0.9
Oncoming vehicle passed	1			32		1	34	30.1
Vehicle ahead								
Vehicle behind								
Curve	1R			5L 3R			5L 4R	8.0
To signal improper lights or passing								
Subject passing								
No traffic				5			5	4.4
Start or change roads	1			2			3	2.7
Street lights			6				6	5.3
No or dim street lights	3						3	2.7
Fog or snowfall	1					3	4	3.5
To reduce glare								
Momentary, no Apparent cause								
No apparent cause				1			1	0.9
Prompted by experimenter								
Straight no event								
To see pedestrian/vehicle/object/sign								
Passed pedestrian/vehicle/object/sign								
Approach entrance								
Entrance ramp								
Merge								
Approach exit ramp								
Exit ramp								
Total column frequency	7	0	6	49	0	51	113	100.0
Total column percent	6.2	0.0	5.4	43.4	0.0	45.1	100.0	

Note - L=Left, R=Right, P=Pedestrian, V=Vehicle, O=Object, S=Sign, Ps=Passing, Lt=Lights.

TABLE 6. Beam Selection Sequence by Event Using the Three-Beam Headlighting System on Urban Roads. Data for 10 Drivers.

Event	Beam Changes						Total Row Frequency	Total Row Percent
	L→M	L→H	M→L	M→H	H→L	H→M		
Vehicle coming over hill								
Vehicle oncoming								
Vehicle flashes beams								
Oncoming vehicle passed								
Vehicle ahead			1				1	3.6
Vehicle behind								
Curve								
To signal improper lights or passing		2Lt					2Lt	7.1
Subject passing								
No traffic								
Start or change roads			3				3	10.7
Street lights			7				7	25.1
No or dim street lights	3						3	10.7
Fog or snowfall								
To reduce glare								
Momentary, no apparent cause			2	1			3	10.7
No apparent cause	1		1		2	1	5	17.9
Prompted by experimenter	2						2	7.1
Straight no event								
To see pedestrian/vehicle/object/sign	2P						2P	7.1
Passed pedestrian/vehicle/object/sign								
Approach entrance								
Entrance ramp								
Merge								
Approach exit ramp								
Exit ramp								
End of ramp								
Total column frequency	8	2	14	1	2	1	28	100.0
Total column percent	28.6	7.1	50.0	3.6	7.1	3.6	100.0	

Note - L=Left, R=Right, P=Pedestrian, V=Vehicle, O=Object, S=Sign, Ps=Passing, Lt=Lights.

It should be noted that only 28 beam switches occurred on the urban road sections, or an average of 2.8 changes in beams per driver. Most of these involved, therefore, changing from the mid beam to the low beam as the urban section is entered and some use of the mid beam where street lighting was considered to be of poor quality.

Driving Test: The Use of the Beams. The foregoing results showed the events which precipitated switching from one beam to another, but do not provide information of the exposure of each beam in these conditions. There was no attempt made to measure the actual exposure of a beam in each condition, such as by the time for which a beam was used in each condition or the frequency with which a beam was in use as each event occurred. However, some indication of the actual utilization of each beam can be obtained from the beam switching results shown in Tables 4-6. Clearly, those beams between which most of the switching occurred must be the ones that are in use either on a long- or short-term basis. Thus, Table 4 shows that most of the beam switching occurred between the mid and high beams. Therefore, it is evident that these two beams are potentially the ones mostly used on the freeway sections. The indication from this table is that high the beam was used for probably relatively short time durations such as on curves, to signal improper lights of an oncoming vehicle, when there was no opposing traffic or preceding traffic, and at approaches to entrance and exit ramps. By comparison, the mid beam is probably used for longer time periods, since switching from high to mid beam occurred in instances such as when there was an oncoming vehicle, there was a vehicle ahead, the driver was passing another vehicle, and when merging. In addition, these data are substantiated by the records made by the experimenter who reported that on the freeway section most of the driving was done using the mid beam.

Similarly, on the two-lane rural roads the mid beam was also used more than any other beam. There appeared to be somewhat greater use of high beam on the rural road section than on the freeway as shown by the fairly large number of switches from mid to high beam when an oncoming vehicle had passed.

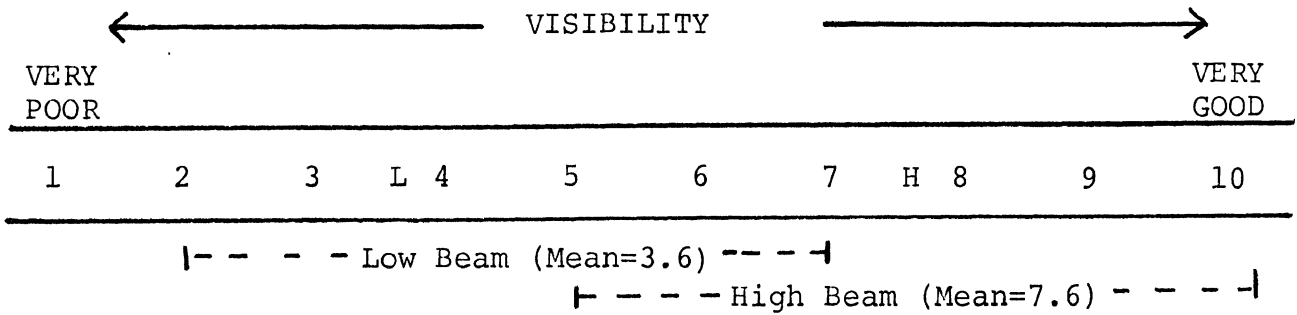
On the urban road sections, the experimenter reported that the low beam was used almost exclusively except for some streets where the level of the fixed illumination was perceived to be low, in which case the mid beam was requested by the drivers.

Ratings of Effectiveness of Beams. Prior to the driving test each subject rated the conventional low and high beams in terms of the visibility they provide and the glare effects they create, using a ten-point rating scale. This scale, and the dispersion and mean of the ratings of the subjects is shown in Table 7. This indicates that subjects rated the high beam as providing better visibility than the low beam, and with the high beam providing greater glare than the low beam, as would be expected. Analysis of variance of the ratings showed that the mean visibility ratings were significantly different as were the mean ratings of the glare effect of the high and low beam.

After the subjects had participated in the driving test and had an opportunity of using the three-beam system, as well as having been exposed to it when driven towards them, they completed a similar set of ratings using the scale shown in Table 8. Analysis of variance and a Newman-Keuls test showed that the mean visibility rating of the high beam was significantly greater than for the mid or low beams. Visibility effectiveness ratings of the mid beam were significantly greater than the low beam. On the other hand, the high beam was rated as creating significantly more glare than either the mid or low beams, which were not rated significantly different in glare.

TABLE 7. Effectiveness Ratings of a Conventional Two-Beam Headlamp System.

Would you please rate your normal LOW and HIGH beams on a 10-point scale from VERY POOR VISIBILITY to VERY GOOD VISIBILITY. Put an L and an H respectively where you would rate your beams on the visibility scale.



Would you please rate your normal LOW and HIGH beams on a 10-point scale from NO GLARE to EXTREMELY GLARING. Put an L and an H respectively where you would rate your beams on the visibility scale. Your rating should reflect the amount of glare that you think oncoming drivers receive.

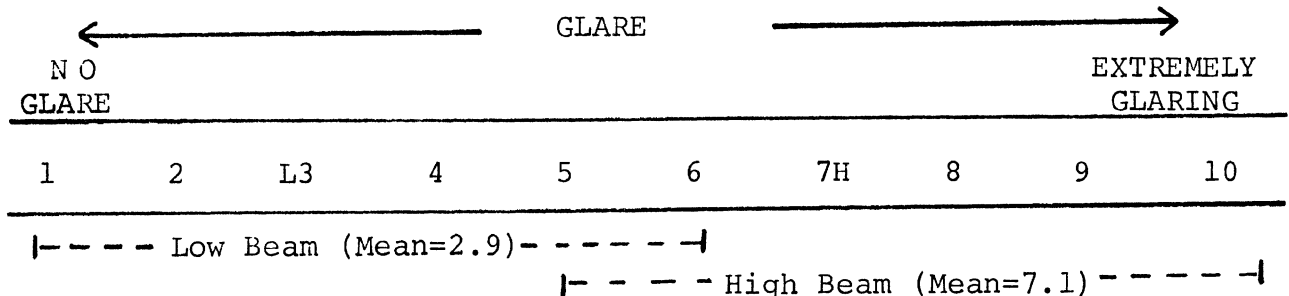
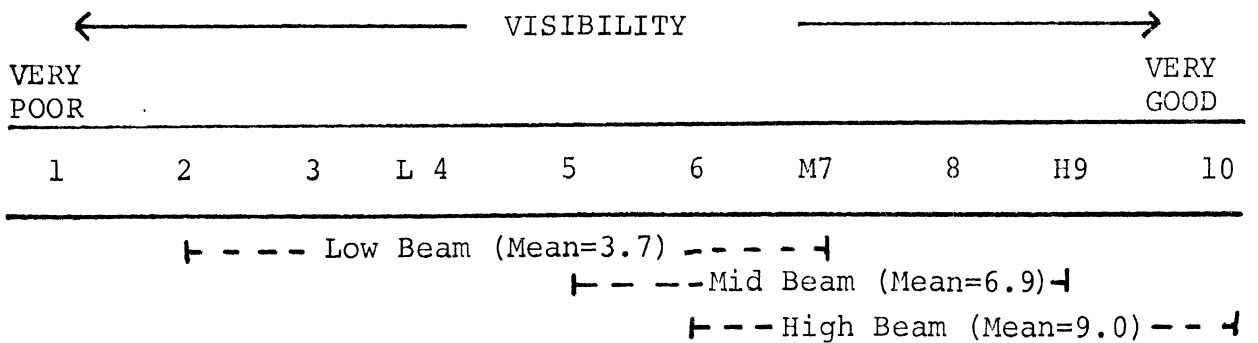
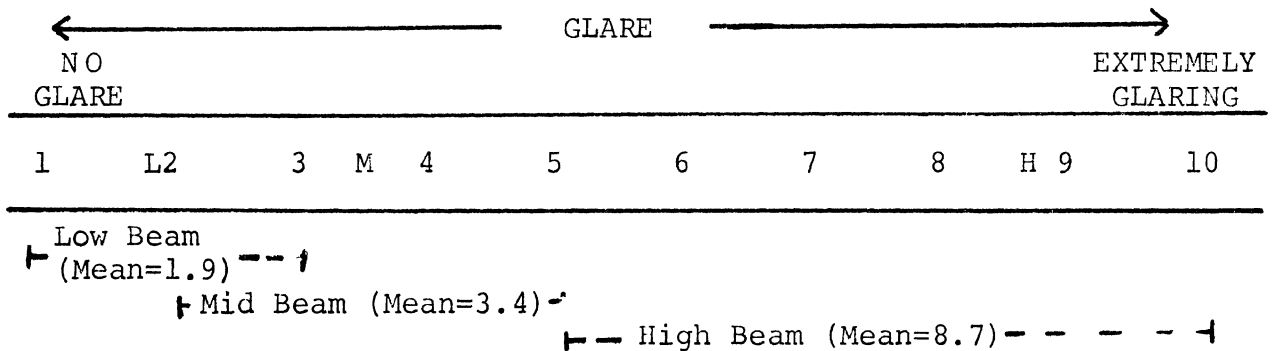


TABLE 8. Effectiveness Ratings of a Three-Beam Headlamp System.

Please rate the LOW, MIDDLE and HIGH test beam on a 10-point scale from VERY POOR VISIBILITY to VERY GOOD VISIBILITY. Put an L, M and H respectively where you would rate your beams on the visibility scale.



Please rate the LOW, MIDDLE and HIGH test beams on a 10-point scale from NO GLARE to EXTREMELY GLARING. Put an L, M and H respectively where you would rate your beams on the glare scale. Your rating should reflect the amount of glare that you think oncoming drivers receive.



Subjective Comments on Preferred Switching Modes. The subjects were asked a number of questions concerning their preferences for beam switching and feedback displays, among three switching options. These options consisted of (1) a pressure-operated foot switch, which could be put into one of three positions; (2) a two-position foot switch for beam selection combined with a two-position dash-mounted, push/pull switch for choosing the pair of beams that can be selected with the foot switch, and (3) a three-position column-mounted, turn signal lever stalk, which moves in a horizontal plane. In summarizing the preferences of this sample of ten drivers, the primary statement they made was used and is shown in Table 9a. These responses are summarized in Table 9b, showing that half the subjects felt they would prefer a column-mounted lever, with the remainder having reservations about this type of switch or preferring the other two arrangements.

DISCUSSION OF PHASE I STUDIES. The findings of these studies have indicated that subjects would make use of a mid beam if it were provided as part of a three-beam system. This is partly derived from the responses to the beam usage questionnaires (Tables 1 and 2) which indicate that in many driving situations where the low beam is now used, the drivers would use the mid beam to obtain improved visibility. At the same time, they did not believe that the use of the mid beam would increase the glare to oncoming drivers appreciably.

In the driving test, subjects demonstrated that they preferred to use the mid beam in most of the driving they carried out on the freeway and also on two-lane rural roads. Thus, they substantiated their subjective reports of the manner in which they would use a mid beam. Therefore, it could be concluded that one important finding of this study is that the mid beam would likely be used by drivers in conditions where they now use the low beam, and where the low beam provides inadequate visibility.



TABLE 9a. Primary Statements of Switch Preferences of 10 Drivers

---

Subject No.	Primary Statement
1	I definitely prefer a column lever.
2	I prefer the column location - I've used both.
3	I would like a column lever - I've used both.
4	The column location is best choice of the three but may be confusing.
5	I really like the floor-dash combination - I'm sure the column lever is also practical.
6	The column is the best choice but stalks can become too complex.
7	I prefer the dash-floor switch combination.
8	I'm inclined to a cycling footswitch not operated by pressure level - a column stalk would be OK.
9	The column stalk would be better and the easiest to get used to.
10	The column stalk is a good location and allows fingertips to be used to push it in and out.

---

Note - Subjects were given the following choices:

- a) a pressure-operated 3 position footswitch.
- b) a 2-position footswitch dimmer combined with a 2-position dash push-pull beam selector, i.e. toward the driver would give the low or middle beam choice and away from the driver would give the middle or high beam choice. The dimmer would select between the pair of beams.
- c) a 3-position, horizontal turn lever stalk-low toward driver, high away from driver with mid in between.

TABLE 9b. Summary of Preferences Among Three Beam Switching Systems.

Number of Subjects	Supporting These Statements Regarding Switching Systems
5†	Prefer a column stalk like a 3-position horizontal turn signal lever (1, 2*, 3*, 9*, 10*)
2	Prefer column stalk with reservations (4, 6)
2	Prefer floor-dash combination (5, 7)
1	Prefer a cycling footswitch (8)

† Two of the first five have two cars, one with a column stalk and one with a footswitch.

\* These subjects have used a column-mounted stalk dimmer.

Another major objective of the driving studies was to provide information of the sequences in which beams are selected in a three-beam system. The findings of this study show that on freeways and two-lane rural roads most of the beam selections are between the mid and high beams. On these roads the change from mid to high beam sometimes occurred on curves, indicating that a switch should allow this to be readily accomplished. Similarly, the need to be able to return to mid beam from high beam was also shown, so that this switching should be accomplished with ease. On the urban road sections the bulk of the switching occurred between low and mid beams, primarily when either entering or leaving the urban section having fixed illumination. High beam was used to signal improper lights on other vehicles on a few occasions. Similarly, there was some use made of the low beam on the freeway section, such as when encountering fog or snowfall. The first of these three types of beam uses is not considered to be particularly significant for safety, and does not require as rapid a switching as some other conditions. It would appear feasible, therefore, to achieve safe beam selection if only two beams were available to a driver at any one instant by the major beam selection mode, such as a foot-operated switch or a hand-operated switch. This does not imply that the use of a single switching concept by which any one of three beams could be directly obtained is not desirable, but implies that it may not be necessary for the driver's convenience or for safe operation of the vehicle.

The subjective impressions of the drivers in evaluating three specified switching concepts indicate that half of the subjects would prefer a lever type of switch operated by the hand. However, two drivers indicated that such a concept may be confusing, and another preferred a switching mechanism incorporating operation by the foot. Those data are quite tenuous, since they are based on a subjective evaluation without

actual experience with the switches specified with a three-beam system, for a few subjects. Thus, those data are interpreted as providing only some initial indications of potential preferences for switching concepts.

There are many other considerations that enter into the development of a suitable switching concept for a three-beam system. One of these, is the compatibility that should exist between vehicles that will be equipped with a three-beam system and those that will still use a two-beam headlighting system. It would be desirable if the major features of the switching for either a three-beam system or a two-beam system are similar to each other.

The major findings of these studies conducted in Phase I indicate that drivers will use a mid beam on freeways and two-lane rural roads, and that a suitable switching concept would be one which either allows any one of the three beams to be readily selected or in which convenient selection is provided between the low and mid or high beams on urban roads, and the mid and the high beams on other roads. It would probably be advantageous to use the split of low and high beams, and mid and high beams, since this would satisfy the requirements for safe beam use and be compatible with the present, two-beam system. This information is considered valuable to aid in structuring the analysis developed for the evaluation of beam switching concepts, described in Phase II of this study.

#### PHASE II: EVALUATION OF THREE-BEAM SWITCHING CONFIGURATIONS.

CURRENT PRACTICE IN BEAM SWITCHING. The intended uses of the beams suggests that it should be possible to switch conveniently, at least between mid and high beams on expressways and rural roads. Low beams are appropriate for urban use although if it is possible for beams to be misused then it should be

possible to switch to high beam for such signaling purposes. Rural expressway exits may require high beams for successful high-speed exit maneuvers. Therefore, a middle to high beam shift may be essential.

Designing a switching system for a three-beam headlamp system without redesigning the entire vehicle control and display system requires care in control and display (C/D) modifications. One consideration must be C/D system compatibility with present C/D systems. This is not an easy undertaking due to the lack of commonality of C/D systems (Krumm et al., 1972). Another difficulty is the reported use of inappropriate controls and displays (Woodson et al., 1969). However, an attempt can be made to produce C/D system modifications that are consistent with current commonality where it does exist in a proper manner. One consistent factor found by Woodson et al. (1969) was the location of lighting controls to the left of the steering wheel and usually on the lower left dash. Other controls which were found to be very consistent across models were the vertically activated turn lever on the left of the steering column and the foot-operated beam selector switch on the left side of the floor near the firewall.

Good control operability minimizes inadvertent control actuation, control selection errors, control activation errors, time to locate the control, and time to operate the control. A good display minimizes time to locate the display, and information acquisition time and errors. These are desirable C/D features.

Human factors and anthropometric considerations enumerated by Morgan, Cook, Chapanis, and Lund (1963), McCormick (1964) and Damon, Stoudt, and McFarland (1966) should be applied to control and display design. Among specific considerations that should enter into the design of a switching system for a two-

beam headlighting system are the following two:

1. It should not be possible to inactivate the headlights inadvertently.

2. It should be possible to change beams with a single motion.

Presently three high/low beam switching systems predominate the automotive field. The push/push foot switch satisfies the above criteria for beam switching systems. However, it tends to be deficient on some human factors criteria such as ease of location and thereby ease of operation, and feedback. These deficiencies appear as variability of location, positioning requiring excessive or awkward upward leg movement for some people, and lack of two positions distinguishable by touch or vision. The pull/pull column lever also satisfies the two specific criteria for beam switching systems. Its location and movement are appropriate except for the lack of distinguishable beam positions. The push/pull column lever differs from the pull/pull column lever by providing two distinct beam positions which provide proprioceptive and visual feedback. Thus, the latter system does not have the problems associated with the foot switch or the pull/pull column lever.

The present headlamp beam displays have several shortcomings. First of all, they do not indicate if the low beams are activated, resulting in headlamps being left on in the daytime unintentionally, and in some vehicles being driven without lights or with only parking lights on roads illuminated by street lamps at night. This could be alleviated by connecting the instrument panel illumination to the headlamp switch position instead of the parking lamp position, providing no vehicle usage is envisioned which requires panel illumination and parking lamps only. Another solution could be to provide a low-beam indicator.

The high-beam indicators are presently designed to provide

information on demand at night. That is, the display is not highly attention-getting, but the information is provided. The color used to indicate high beam should be standardized if it is retained as a beam coding concept, as three different colors were found to be in use by Woodson et al. (1969). The location of the beam indicator near the speedometer not only provides information on demand, but also provides a means of periodically updating the beam status information when the speedometer is read.

The headlamp activation switch is nearly always a round knob on the lower left dash. This should be easily distinguishable from other knobs in that vicinity, be within reach of all drivers, and have distinct parking lamp and headlamp positions. This switch is usually easy to locate, easy to operate, and provides proprioceptive feedback.

SOME EXAMPLES OF THREE-BEAM SWITCHING CONCEPTS. The present beam switching systems can be modified to provide switching for three-beam systems. Several possible modifications are shown in Figures 3-15 (Appendix 2).

Configuration A (Figure 3) would use the foot switch to select between two beams, with a two-position push/pull switch determining whether the beam pair choice\* is high/mid or high/low. To prevent inadvertent inactivation of the headlamps, the switch used to select between a pair of beams should be separate from the one used to activate headlamps or parking lamps. The parking lamps could be activated by a position on the headlamp activation switch (e.g., OFF-PARK-HEADLAMP).

Configuration B (Figure 4) replaces the foot switch with a column lever. Pulling the lever towards the driver alternately selects between two beams with the push/pull knob position de-

---

\*Based on the beam usage study described earlier in this report.

termining the beam pair available, i.e., high/mid or high/low. A separate parking lamp and headlamp activation switch would be used, similar to Configuration A.

Configuration C (Figure 5) is identical to B except the lever position provides feedback by selecting low or mid beam when pulled toward the driver and high beam when pushed away from the driver. The choice of beam pairs is again determined by the position of the push/pull switch.

Configuration D (Figure 6) allows the driver to select between low and high or mid and high by pulling the column lever toward him. The choice of beam pairs is determined by the status of the foot switch. The headlamp activation can be accomplished by an OFF-PARK-HEADLAMP push/pull panel knob.

Configuration E (Figure 7) is similar to D except the pull lever is replaced with a push/pull lever. Thus, the driver selects the low or mid beam by pulling the lever toward him and high beam by pushing the lever away from him. The beam pairs available by moving the lever are determined by the status of the foot switch. The headlamp can be activated by the push/pull OFF-PARK-HEADLAMP switch.

Configuration F (Figure 8) reverses the roles of the column stalk and foot switch. Thus, the foot switch is used to select the beams and the column lever position determines the pair of beams available for selection.

Configuration G (Figure 9) replaces two, two-position switches with a three-position column lever which moves in a horizontal plane to select low, mid, or high beam. Low beam would be obtained by moving the lever toward the driver, with mid beam being midway between low and high beam positions. The present headlamp activator switch functions are retained.

Configuration H (Figure 10) uses a three-position column



lever which moves in a triangular pattern to select the three beams. A separate switch is used to activate the lamps.

Configuration I (Figure 11) uses a foot switch for beam selection. The alternate is determined by the setting of the panel rotary switch which is also used for headlamp activation. On the left are detents for off and park, and on the right are detents for the low/high choice and the mid/high choice.

Configuration J (Figure 12) uses a push/pull panel knob for activation. This knob can be shifted to one position to provide a low/high choice and another position to provide a mid/high choice. Beam selection is accomplished by a foot switch.

Configuration K (Figure 13) uses three lighted pushbuttons horizontally placed on the steering column hub which remains in a fixed position as the steering wheel rotates. A separate switch is used to activate the lamps.

Configuration L (Figure 14) uses three lighted pushbuttons mounted vertically on a support just past the left edge of the steering column. The same concept could be used with the pushbuttons to the right of the steering column or aligned horizontally. A separate switch is used to activate the lamps.

Configuration M (Figure 15) is a three-position foot switch which contains detents such that in its uppermost position low and high beam are available with light pressure applications and mid beam is obtained by exerting a heavy pressure application. A successive application of heavy pressure will put the switch back in the low and high beam availability mode.

EVALUATION OF SWITCHING CONCEPTS BY DESIGN CRITERIA. Many other three-beam switching configurations could be considered than the thirteen examples described. It should be obvious that the number of potential systems is nearly limitless if one allows

door, dash, console, and other locations and combinations thereof, and other types of switches. What is needed in this instance is a suitable set of design criteria by which one can delimit the number of three-beam switching designs to be considered.

Recently, Woodson et al. (1969) and Krumm et al. (1972) have sought to develop a suitable set of criteria. Woodson et al. used previous aviation and aerospace studies as a basis for enumerating relevant criteria. Krumm et al. on the other hand, used functional considerations which were weighted for importance as relevant criteria. Both of these approaches have merit and have therefore been used in the present effort. Additions and modifications were made to these relevant criteria to make them more inclusive and applicable to automotive usage.

Development of Evaluation Criteria. The concepts contained in the "Reference Criteria List" (Woodson et al., 1969) and the "Concept Evaluation Criteria" (Krumm et al., 1972) were presented to five HSRI staff members with experience in switching design. These individuals were asked to assign a rating to each of 44 statements, based on its importance for optimum automobile or truck control-display use. Ratings were described as follows:

1. Essential - these design criteria must necessarily be satisfied to avoid hazardous situations.

2. Primary - these design criteria should be satisfied as they will contribute the most to maximizing correct control/display usage.

3. Secondary - these design criteria would increase appropriate control/display usage, but would not affect control/display usage as much as the primary criteria.

4. Hardware - these criteria are not really design criteria because their effects are judged to be highly dependent on the hardware that may be used to implement them.

5. None of these - not criteria generally applicable to automotive vehicles.

The ratings assigned to each statement by the five raters were examined for inter-rater agreement. Those statements that received ratings which differed across more than three categories were discarded in order to retain statements which were rated reasonably similarly by each rater.

Thus, the resulting scale of remaining statements should be acceptably reliable.

The remaining statements were assigned a weight which is the sum of the ratings it was assigned by the five raters, where a rating of "essential" was weighted 5, "primary" was weighted 3, and "secondary" was weighted 1. The remaining two statements were weighted zero. Four statements that received a summed weight of less than 7 were dropped, since they are clearly of little relevance, even though they were reliable.

Based on the summed numerical ratings, a grouping of statements was made by weighted importance rating categories. These statements of design concepts are shown in Tables 10-13 grouped by essential, primary, secondary and tertiary importance weights, respectively.

TABLE 10. Design Concepts of Essential Importance.

1. Controls should be so arranged that their operation does not overload one hand or foot. [16,33,71]<sup>1</sup> (2,7,10,13,14,15,16,29,31)<sup>2</sup>
2. Controls which occasionally require actuation while the vehicle is in motion should be within reach of all drivers from their normal driving position even if they are wearing optional restraints. [5]<sup>4</sup>
3. It should not be possible to inactivate the headlamps inadvertently. [1]<sup>4</sup>
4. Controls which must be reached quickly (as in an emergency) should be located near the hand or foot by which they will be operated. [13]<sup>1</sup> (10,13,16,23,28,31)<sup>2</sup>
5. It should be possible to get to a beam of less glare from any beam producing objectionable glare with a single motion. [2]<sup>4</sup>
6. It should be possible to get to a beam providing greater visibility from any beam producing less visibility with a single motion for safety purposes. [10]<sup>4</sup>

---

Note - The footnotes below apply to Tables 10-13.

<sup>1</sup>Man Factors Inc. (Woodson et al, 1969), "Reference Criteria List".

<sup>2</sup>Man Factors Inc. (Woodson et al, 1969), "Criterion Compilation References".

<sup>3</sup>Essex Corporation (krumm et al, 1972), "Concept Evaluation Criteria".

<sup>4</sup>Design concepts added by HSRI.

TABLE 11. Design Concepts of Primary Importance. (Continued)

1. All controls and displays should be identifiable by their shape, location, color and/or by the labels associated with them. [1]<sup>1</sup> (2,4,6,7,8,10,16,29,31,33)<sup>2</sup>
2. Controls which turn a system ON should move UP, to the right, or clockwise for ON; in the opposite direction for OFF. [36]<sup>1</sup> (29,31)<sup>2</sup>
3. The preferred area for location of displays centers about the normal line of sight. Critical displays should be located so that the operator does not have to turn his head to see them. Horizontal arrangements are preferred for the seated operator. [5]<sup>1</sup> (4,26,29)<sup>2</sup>
4. Controls used most frequently (by the hands) should be located between waist and shoulder height. [11]<sup>1</sup> (16,31)<sup>2</sup>
5. Minimum problems with arm/leg reach. [10]<sup>3</sup>
6. Degree to which the operation interferes with speed control of the vehicle. [13]<sup>3</sup>
7. Controls should provide feedback while being operated, i.e. provide proprioceptive cues. [6]<sup>4</sup>
8. Controls and displays that are used most frequently should be located in prime positions relative to convenience. [2]<sup>1</sup> (10,11,14,23)<sup>2</sup>
9. Displays and controls should be illuminated if they are to be used at night or under low ambient light conditions. [38]<sup>1</sup> (7,10,13,16)<sup>2</sup>
10. Control will not be inadvertently activated. [5]<sup>3</sup>
11. Less likelihood of substitution errors (confusion of one control with another). [6]<sup>3</sup>

TABLE 11. Design Concepts of Primary Importance. (Concluded)

12. If controls are not illuminated at night, they should be within blind reach. [4]<sup>4</sup>
13. Controls should be located so they are within "comfortable" reach. The operator should not have to utilize maximum reach limits unless absolutely necessary because of lack of space for locating controls in more convenient positions. [53]<sup>1</sup> (26,28,31)<sup>2</sup>
14. Foot controls should only be used where large applications of force are required, where a large amount of displacement is required, where only gross movements are required, and/or where the operator is likely to have both hands occupied. [74]<sup>1</sup> (7)<sup>2</sup>
15. All labels should be visible under all conditions of use (i.e., day or night). [24]<sup>1</sup> (16,29,33)<sup>2</sup>
16. Capable of operating beam switch while turning the steering wheel. [3]<sup>3</sup>

TABLE 12. Design Concepts of Secondary Importance.

1. It should be possible to return with one motion to an original beam after dimming. [3]<sup>4</sup>
2. Controls should provide display status feedback. [9]<sup>4</sup>
3. Control activation takes minimum time. [4]<sup>3</sup>
4. Minimum requirements for removing a hand from the wheel. [8]<sup>3</sup>
5. Certain types of switch controls should have only two positions, e.g., toggle, rocker and push button controls. [43]<sup>1</sup> (13,16,29)<sup>2</sup>
6. When practicable, all levers should be labeled as to function and direction of motion. [37]<sup>1</sup> (14,16,29,33)
7. All controls should imply the manner in which they are to be operated by their appearance and/or by the labels associated with them. [2]<sup>1</sup> (2,4,7,29,31,33)<sup>2</sup>
8. Foot-operated push buttons should be used only for non-critical operations. [73]<sup>1</sup> (2,7,16,29,31)<sup>2</sup>
9. Amenable to positive identification coding. [11]<sup>3</sup>

TABLE 13. Design Concepts of Tertiary Importance.

1. Use foot-operated controls if large force application is necessary; hand controls if fine adjustment is required. [48]<sup>1</sup> (13,16,29)<sup>2</sup>
2. Push buttons arranged in a horizontal array are preferred to a vertical array. [79]<sup>1</sup> (13,16,29)<sup>2</sup>
3. Labels should not be placed on the surface of a control if movement of the control will obscure the label or cause it to appear other than right side up. [31]<sup>1</sup> (7,10,33)<sup>2</sup>
4. Capability of being operated and monitored without direct visual access. [1]<sup>3</sup>
5. Capable of selecting any of 3 beams with a single motion. [2]<sup>3</sup>
6. Minimum exertion of the part of the driver. [9]<sup>3</sup>
7. Requirements for panel area for controls are minimal. [14]<sup>3</sup>
8. Controls should provide visual status feedback. [7]<sup>4</sup>
9. Controls should provide tactile status feedback. [8]<sup>4</sup>



Using the Evaluation Scale. These design concepts were used by the authors to evaluate the three-beam headlamp switching configurations shown in Figures 3-15, Appendix 2. The results of the evaluation are shown in Table 14. In every instance where a switching system could meet a criterion, given thoughtful engineering design, that system was given a plus (+). In instances where a switching system did not meet or probably could not meet the requirement a minus (-) was recorded. Some criteria were not applicable (N/A) to some switching systems and were recorded as such. The results in Table 14 are summarized in Table 15. The total frequency of the criteria that were met by a configuration in each importance subscale are shown in Table 15. These values were weighted arbitrarily by multiplying the total frequencies in the "essential," "primary," "secondary," and "tertiary" subscales by 4, 3, 2 and 1, respectively, reflecting their decreasing importance. The maximum sum of the weighted subscales is 99. The sums of the weighted subscales, also shown in Table 15, were transformed to a percent total score. This represents the percent of the total weighted applicable design characteristics in the scale that were satisfied by the switching configuration.

DISCUSSION OF PHASE II EVALUATIONS. As can be seen in Table 15, systems D, E, F, G, H, K and L met all of the "essential" concepts. Table 15 also shows that these systems met most of the "primary" concepts. While not being of as great importance as the "essential" and "primary" concepts, Table 15 also shows that systems G, H, K and L were rated highest in the secondary and tertiary categories. Systems G, H, K and L were rated highest overall, as shown by the percent total of the weighted ratings.

The results of the evaluation of Configurations A-M can be summarized to show the effectiveness obtained by various switching concepts. The concepts are described below and their

TABLE 14. Evaluation of Three-Beam Headlamp Switching Configurations Using Design Concepts as Rating Criteria.

		Switching Configurations												
		A	B	C	D	E	F	G	H	I	J	K	L	M
Design Concepts of Essential Importance (From Table 10)	1	+	-	-	+	+	+	+	+	+	+	+	+	+
	2	+	+	+	+	+	+	+	+	+	+	+	+	+
	3	+	+	+	+	+	+	+	+	+	-	+	+	+
	4	-	-	-	+	+	+	+	+	-	-	+	+	+
	5	+	+	+	+	+	+	+	+	+	+	+	+	+
	6	+	+	+	+	+	+	+	+	+	+	+	+	-
Design Concepts of Primary Importance (From Table 11)	1	+	+	+	+	+	+	+	+	+	+	+	+	+
	2	+	+	+	+	+	+	+	+	+	+	+	+	+
	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	4	+	+	+	+	+	+	+	+	+	+	+	+	N/A
	5	-	-	-	+	+	+	+	+	-	-	+	+	+
	6	-	+	+	+	+	-	+	+	-	-	+	+	-
	7	+	+	+	+	+	+	+	+	+	+	+	+	+
	8	+	+	+	+	+	+	+	+	-	-	+	+	+
	9	+	+	+	+	+	+	+	+	+	+	+	+	+
	10	+	+	+	+	+	+	+	+	+	+	+	+	+
	11	+	+	+	+	+	+	+	+	+	+	+	+	+
	12	+	+	+	+	+	+	+	+	+	+	+	+	+
	13	+	+	+	+	+	+	+	+	+	+	+	+	+
	14	+	N/A	N/A	+	+	+	N/A	N/A	+	+	N/A	N/A	-
	15	+	+	+	+	+	+	+	+	+	+	+	+	+
	16	+	-	-	+	+	+	+	+	+	+	+	+	+
Design Concepts of Secondary Importance (From Table 12)	1	+	+	+	+	+	+	+	+	+	+	+	+	-
	2	-	-	+	-	-	-	+	+	-	-	+	+	-
	3	-	-	-	+	+	+	+	+	-	-	+	+	-
	4	-	-	-	+	+	+	+	+	-	-	+	+	+
	5	+	+	+	+	+	+	-	-	+	+	+	+	-
	6	N/A	+	+	+	+	+	+	+	N/A	N/A	N/A	N/A	N/A
	7	+	+	+	+	+	+	+	+	+	+	+	+	+
	8	-	N/A	N/A	-	-	-	N/A	N/A	-	-	N/A	N/A	-
	9	-	+	+	-	-	-	+	+	-	-	+	+	-
Design Concepts of Tertiary Importance (From Table 13)	1	+	+	+	+	+	+	+	+	+	+	+	+	+
	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	+	+	N/A
	3	+	+	+	+	+	+	+	+	+	+	+	+	+
	4	-	-	+	-	-	-	+	-	-	-	+	+	-
	5	-	-	-	-	-	-	+	+	-	-	+	+	-
	6	-	-	-	+	+	+	+	+	-	-	+	+	+
	7	+	+	+	+	+	+	+	+	+	+	+	+	+
	8	-	-	-	-	-	-	+	+	-	-	+	+	-
	9	-	-	+	-	-	-	+	+	-	-	+	+	-

Note--For systems using one or two switches, all of the switches and their combinations had to meet the design concept to receive a plus (+) rating. Otherwise a minus (-) rating was recorded unless the design concept was not applicable in which case N/A was recorded.

TABLE 15. Frequency of Acceptable Human Factors Design Characteristics Met by Each Switching Configuration and Sum of Weighted Subscales in Percent.

	Rating	Switching Configurations													
		A	B	C	D	E	F	G	H	I	J	K	L	M	
Rating for Design Concepts of Essential Importance (Subscale Weight, $W_i = 4$ )	+ N/A	5 0	4 0	4 0	6 0	6 0	6 0	6 0	6 0	5 0	4 0	6 0	6 0	5 0	
Rating for Design Concepts of Primary Importance (Subscale Weight, $W_i = 3$ )	+ N/A	13 1	12 2	12 2	15 1	15 1	14 1	14 2	14 2	12 1	12 1	14 2	14 2	12 2	
Rating for Design Concepts of Secondary Importance (Subscale Weight, $W_i = 2$ )	+ N/A	3 1	5 1	6 1	6 0	6 0	7 1	7 1	7 1	3 1	3 1	7 2	7 2	2 1	
Rating for Design Concepts of Tertiary Importance (Subscale Weight, $W_i = 1$ )	+ N/A	3 1	3 1	5 1	4 1	4 1	4 1	7 1	8 1	3 1	3 1	9 0	9 0	4 1	
Sum of Weighted Subscale Positive (+) Ratings	+	68	65	69	85	85	82	87	88	65	61	89	89	64	
Sum of Weighted N/A Ratings	N/A	6	9	9	4	4	4	9	9	6	6	10	10	9	
Percent Total	$\left[ \frac{\sum_{i=1}^4 (W_i \times \text{Freq.} +_i) \times 100}{99 - \sum_{i=1}^4 (W_i \times \text{Freq.} \cdot N/A_i)} \right]$		73	72	77	89	89	85	97	98	70	66	100	100	71

effectiveness ratings are indicated as follows:

A-C are dual controls using a dash switch (push/pull) in combination with a foot switch or column lever, mean rating = 74%.

D-F are dual controls using a column lever in combination with a foot switch, mean rating = 88%.

G-H are single controls using a column lever to obtain all three beams, mean rating = 97%.

I-J are dual controls using a dash switch (rotary or toggle) in combination with a foot switch, mean rating = 68%.

K-L are pushbutton controls located near the steering wheel, mean rating = 100%.

M is a modified foot switch control, rating = 71%.

The switching system groups produced the following rank order, from most effective to least effective: K-L, G-H, D-F, A-C, M, I-J. Therefore, the three-beam selection foot switch (Configuration M) is incapable of meeting many desirable human factors design criteria. The dual controls using a dash switch in combination with another type of switch (Configurations A-C, I-J) are also fairly incapable of meeting many human factors design criteria. The dual controls which use a column lever and a foot switch (Configurations D-F) are fairly capable of satisfying the human factors design criteria. The column-mounted lever controls (Configurations G-H) and the pushbutton controls mounted near the steering wheel (Configurations K-L) which provide access to any of the three beams with one motion, are within blind reach, readily accessible, and provide many types of feedback, are most capable of satisfying the human factors design criteria used in this evaluation.

#### RECOMMENDATIONS AND CONCLUSIONS

A scale that can be readily applied to potential beam switching concepts, and evaluate them for basic conformance to good

human factors design principles should prove useful. It will allow preliminary evaluations to be made of switching concepts for a three-beam system, without the need to build the hardware. By conducting a preliminary screening of potential concepts using a scale such as the one provided by this study, those concepts that appear to be clearly less effective than others can be dropped from further consideration. The concepts that are evaluated as most promising could then be built and evaluated further by subjective and objective driver performance tests. When using the scale the findings of the Phase I studies should be taken into account.

For example, the results of the Phase I studies showed that drivers would utilize a mid beam on two-lane rural roads and on divided highways, and that most switching was done between mid and high beams on these roads, and that low beam was primarily used on urban streets. Therefore, these results indicate that mid or high beams should be available with one switching motion for use on roads other than urban streets. On urban streets low beam must be available. Occasional, brief, use of high beam was reported on urban streets and it may be convenient that it is quickly available. The high beam is also useful in urban driving to assist in reading street names and can be used on poorly lighted residential streets when there is no opposing traffic. One switch position, in a three-beam system, that allows selection between low and high beams would also be desirable for compatibility with headlamp beam selection systems that continue to be in use in vehicles equipped with only two beams.

Results of the analysis of some three-beam switching configurations showed that they differed in overall human factors effectiveness ratings. The most effective system allowed any of the three beams to be selected with one switching motion.

However, a class of switching systems which used a column lever to set the choice of the beam pairs, with a member of the pair selected by switching between the two positions of a foot

switch, or the converse of the above, offers an effective alternative switching concept.

Implementation of the switching concepts found to be potentially effective in this study can take many forms and these methods, and other concepts, should be evaluated analytically, prior to experimental testing of specific hardware configurations and driving evaluations. There can be little doubt that the advantages to all road users of a three-beam system depends upon the development of switching systems that are in accord with good human factors practice.

## REFERENCES

- Damon, A., Stoudt, H.W., and McFarland, R.A. The Human Body in Equipment Design. Harvard University Press, Cambridge, Mass., 1966.
- Hull, R.W., Hemion, R.H., Cadena, D.G., and Dial, B.C. Vehicle forward lighting performance and inspection requirements. U.S. Department of Transportation, NHTSA, Contract FH-11-7342, Southwest Research Institute, Dept. AR-814, 1971.
- Krumm, R.L., Malone, T.B., Kao, H., and Shenk, S. Human Factors Criteria for Vehicle Controls and Displays, Appendix D. Final Report, Contract No. DOT-HS-120-1-174, National Highway Traffic Safety Administration, U.S. Department of Transportation, Essex Corporation, Alexandria, Virginia, Sept. 1972.
- McCormick, E. Human Factors Engineering (2nd ed.). McGraw-Hill, New York, 1964.
- Morgan, C.T., Cook, J.S., Chapanis, A., and Lund, M.W. (Eds.). Human Engineering Guide to Equipment Design. Army, Navy, Air Force Steering Committee, McGraw-Hill, New York, 1963.
- Mortimer, R.G., and Becker, J. Development of a Computer Simulation to Predict the Visibility Distance Provided by Headlamp Beams. Motor Vehicle Manufacturers Association, Contract No. UM-7204-C128, University of Michigan, Report No. UM-HSRI-HF-73-15, 1973.
- Woodson, W.E., Conover, D.W., Miller, G.E., and Selby, P.H. Instrument and Control Location, Accessibility and Identification. Draft Final Report, Contract No. FH-11-6907, National Highway Safety Bureau, U.S. Department of Transportation, Man Factors, Inc., Report No. MF169-106, San Diego, California, July 1969.

## APPENDIX 1

### INSTRUCTIONS FOR THE DRIVING TEST

#### With Subject in Test Car

The vehicle you are driving has a new 3-beam headlamp system. Besides something like the present low and high beams, it also has a mid beam. The mid beam can be used in cases where the low beam does not provide enough light but where use of the high beam would be glaring to other drivers. This mid beam provides light farther than the low beam but does not cause glare for oncoming drivers. Thus, you should use the mid beam in cases where you cannot see far enough with low beam but do not wish to use the high beam. For example, it can be used on two lane, rural roads and expressways. Now to control which beam is in use you need only say which beam you want on--low, mid, or high. I will be talking into a microphone to record when you want to use the various beams, but whenever you want to change beams just interrupt by saying, "now low," "now mid," or "now high." To blink or flash your lights just say "Hi beam then Lo" or "Hi beam then Mid." Any questions?

#### Glare and Visibility Demonstration

Now I will show you what the beams look like on the road in front of you, and then as they are approaching you when you are in your own car so that you can experience their glare effects. (At this point the subject was shown the three beams. He was then seated in his own car while the 3-beam test car was driven towards him at 15 mph to allow the subject to evaluate the glare effects of each beam.)

#### Just Prior to Start of Driving on Test Route

Now, I will tell you where to turn while we proceed with low beams until you request a change. Occasionally, I may ask you if you would like to try a different beam. Say NO if you are satisfied with the beam you are using. Say YES if you would like to try the other one. You can always tell me to change back or to the other beam. (If usage seems inappropriate experimenter asks "Would



you like to try the \_\_\_\_\_ beam now." "Which do you prefer,  
the beam you were using or this one?"

APPENDIX 2

THE THREE-BEAM SWITCHING CONFIGURATIONS  
EVALUATED BY THE RATING SCALE

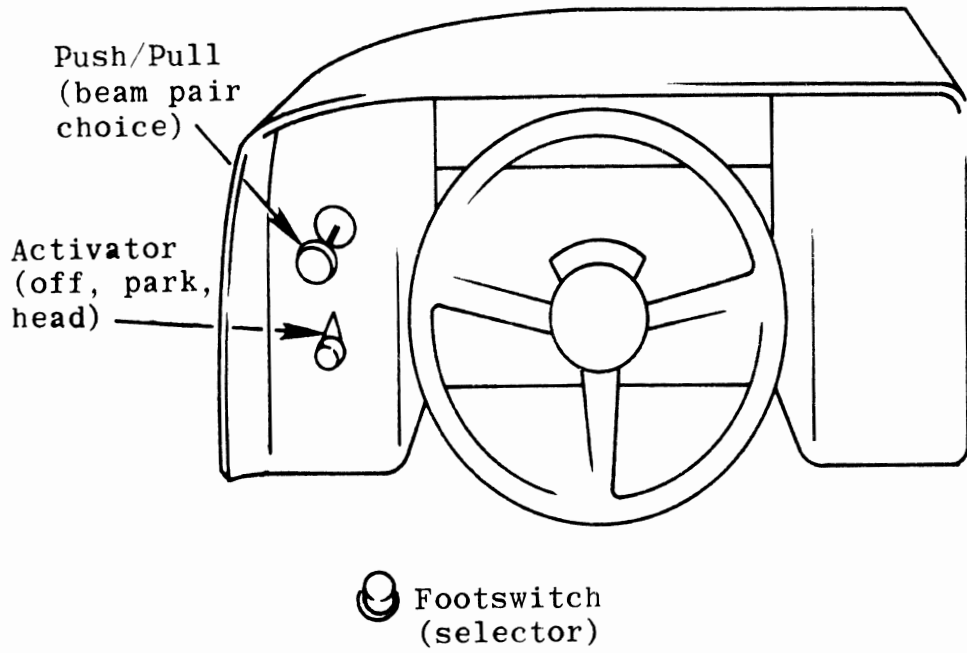


Figure 3. Three-beam switching configuration A.

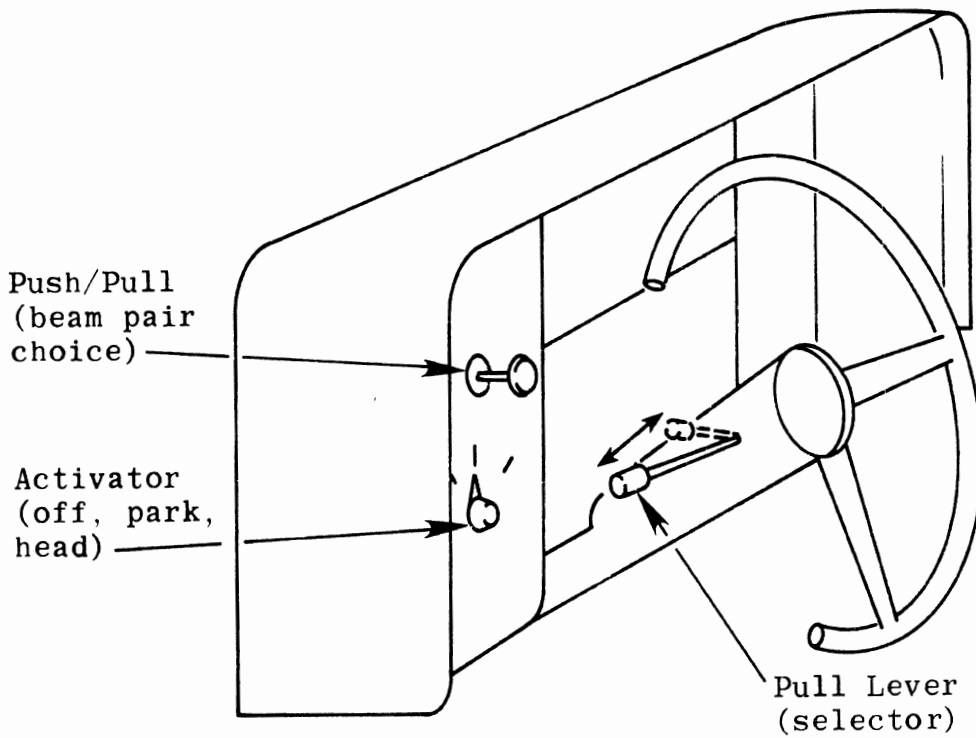


Figure 4. Three-beam switching configuration B.

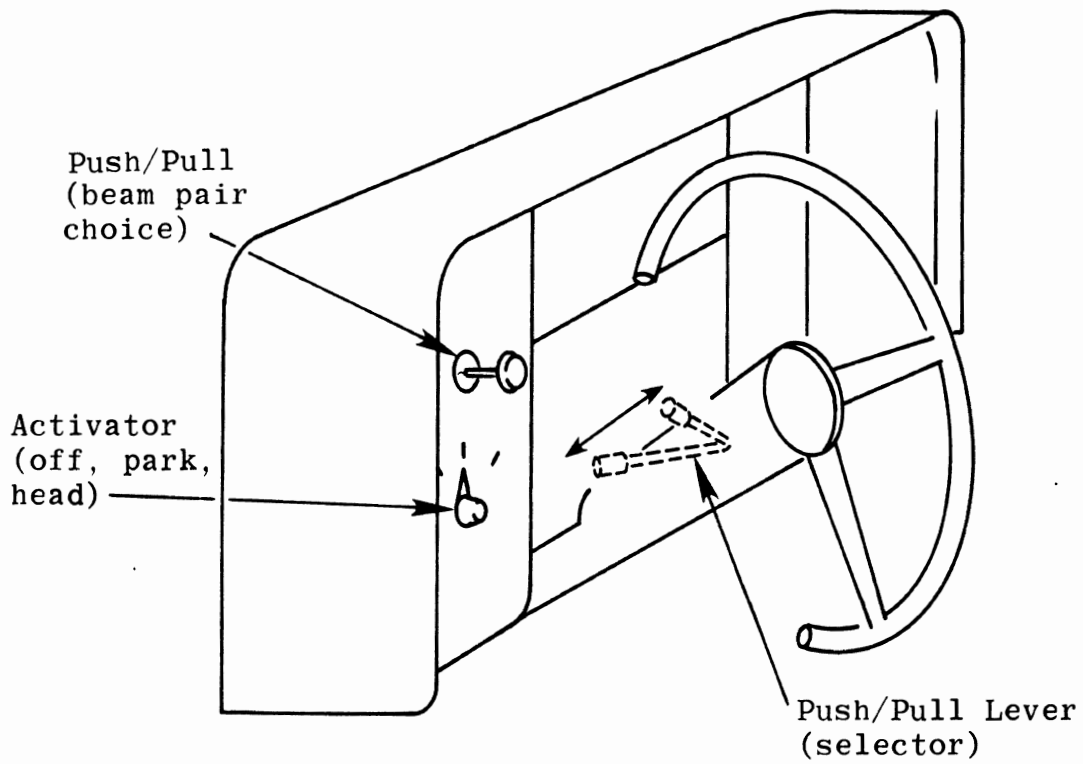


Figure 5. Three-beam switching configuration C.

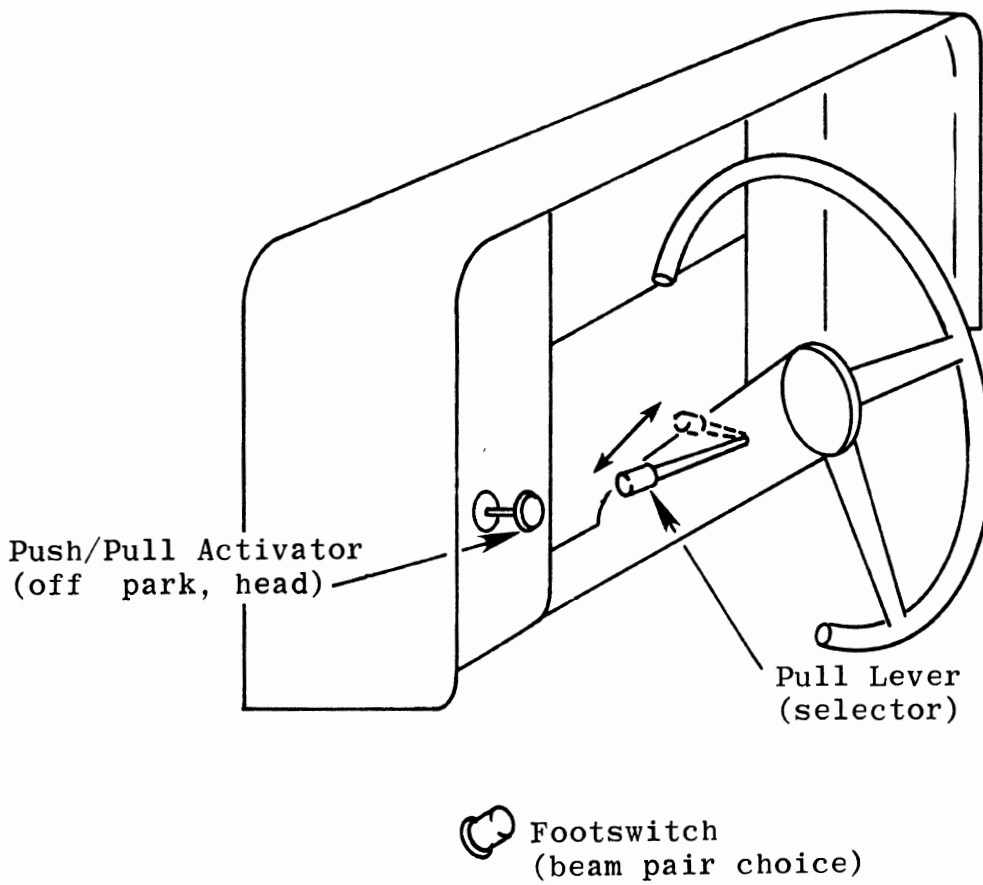
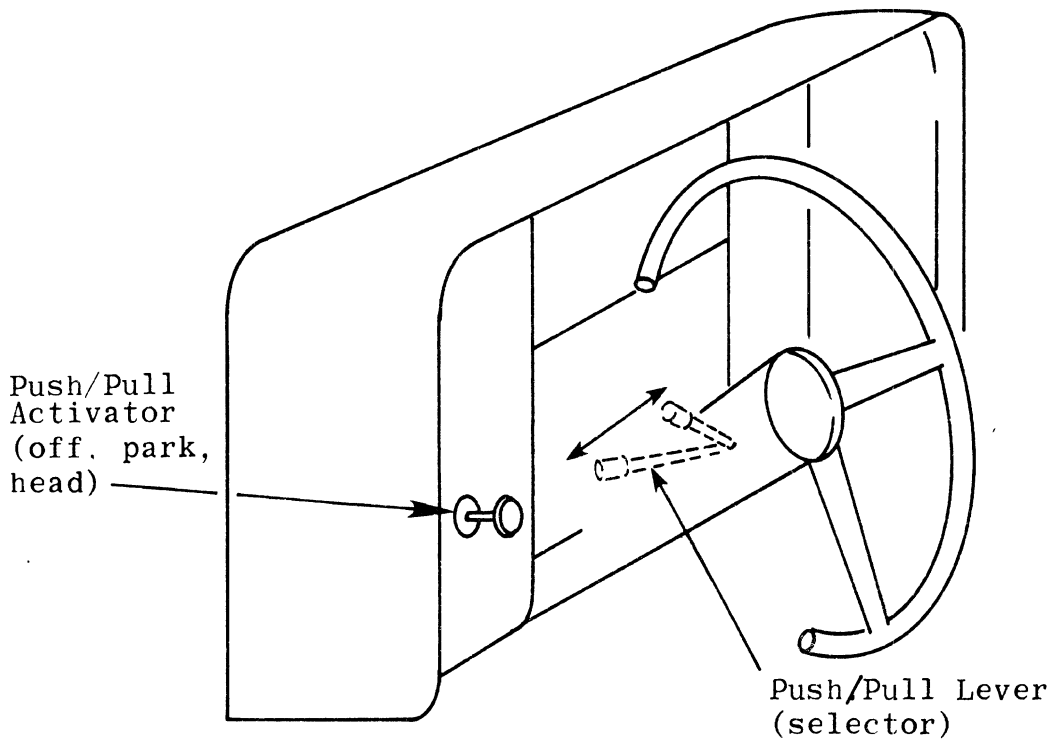
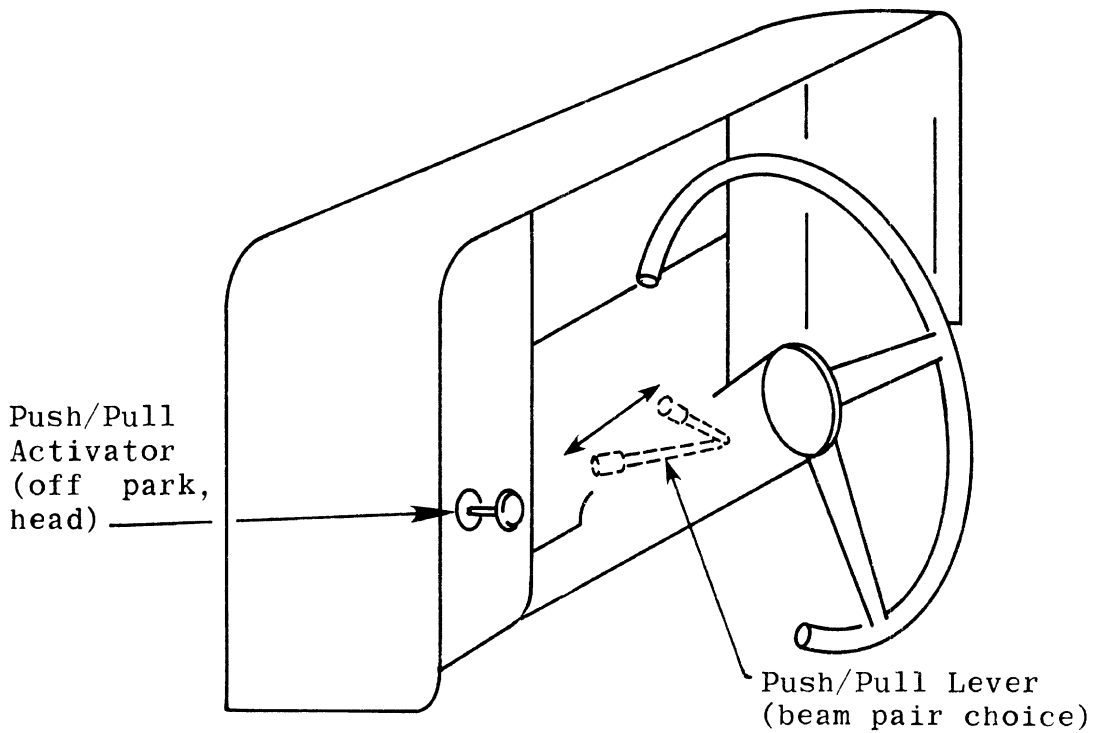


Figure 6. Three-beam switching configuration D.



Footswitch (beam pair choice)

Figure 7. Three-beam switching configuration E.



Footswitch (selector)

Figure 8. Three-beam switching configuration F.

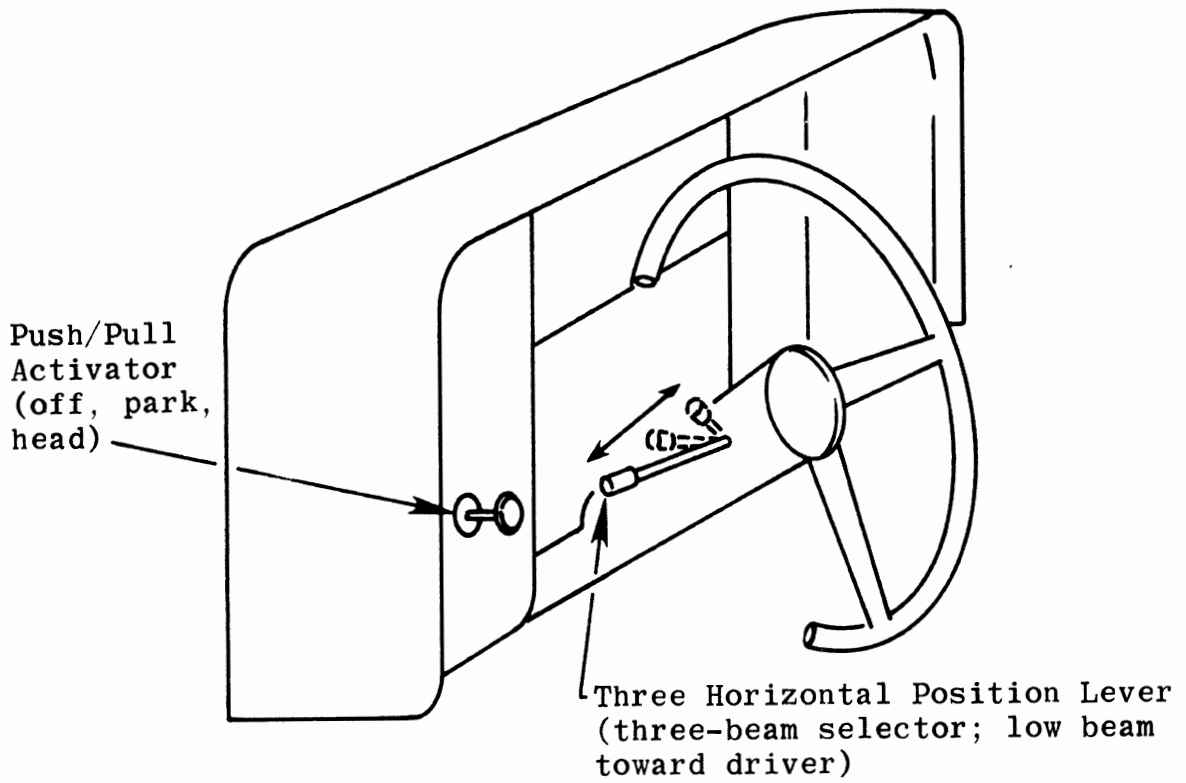


Figure 9. Three-beam switching configuration G.

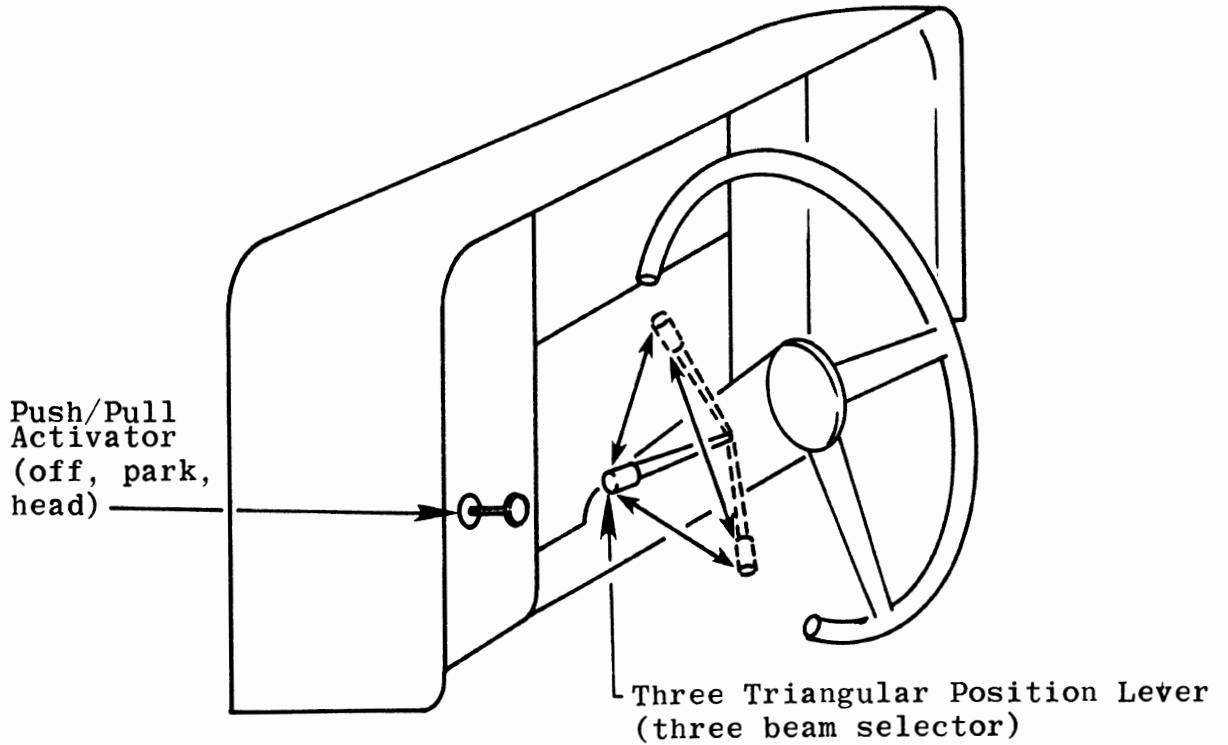


Figure 10. Three-beam switching configuration H.

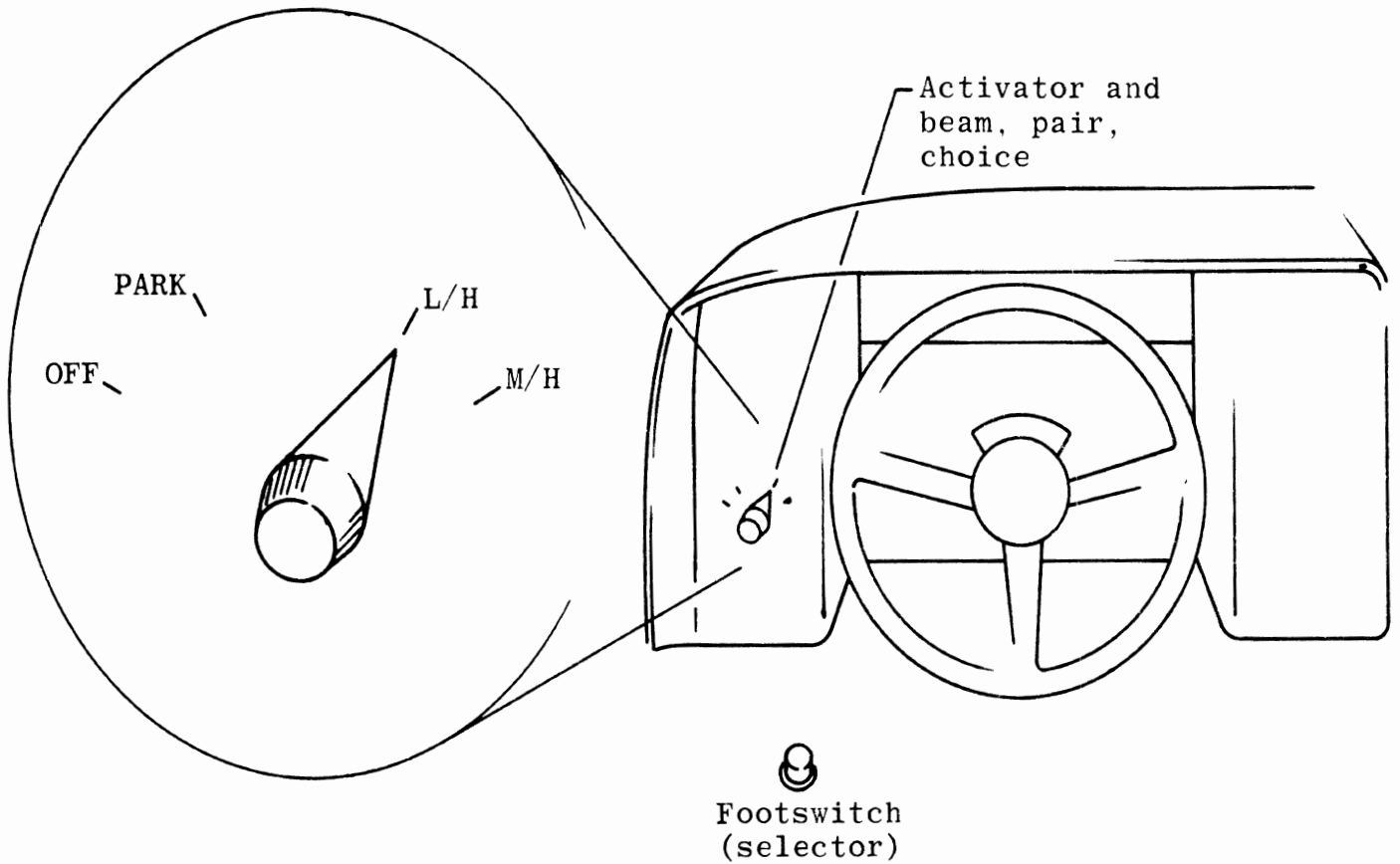


Figure 11. Three-beam switching configuration I.

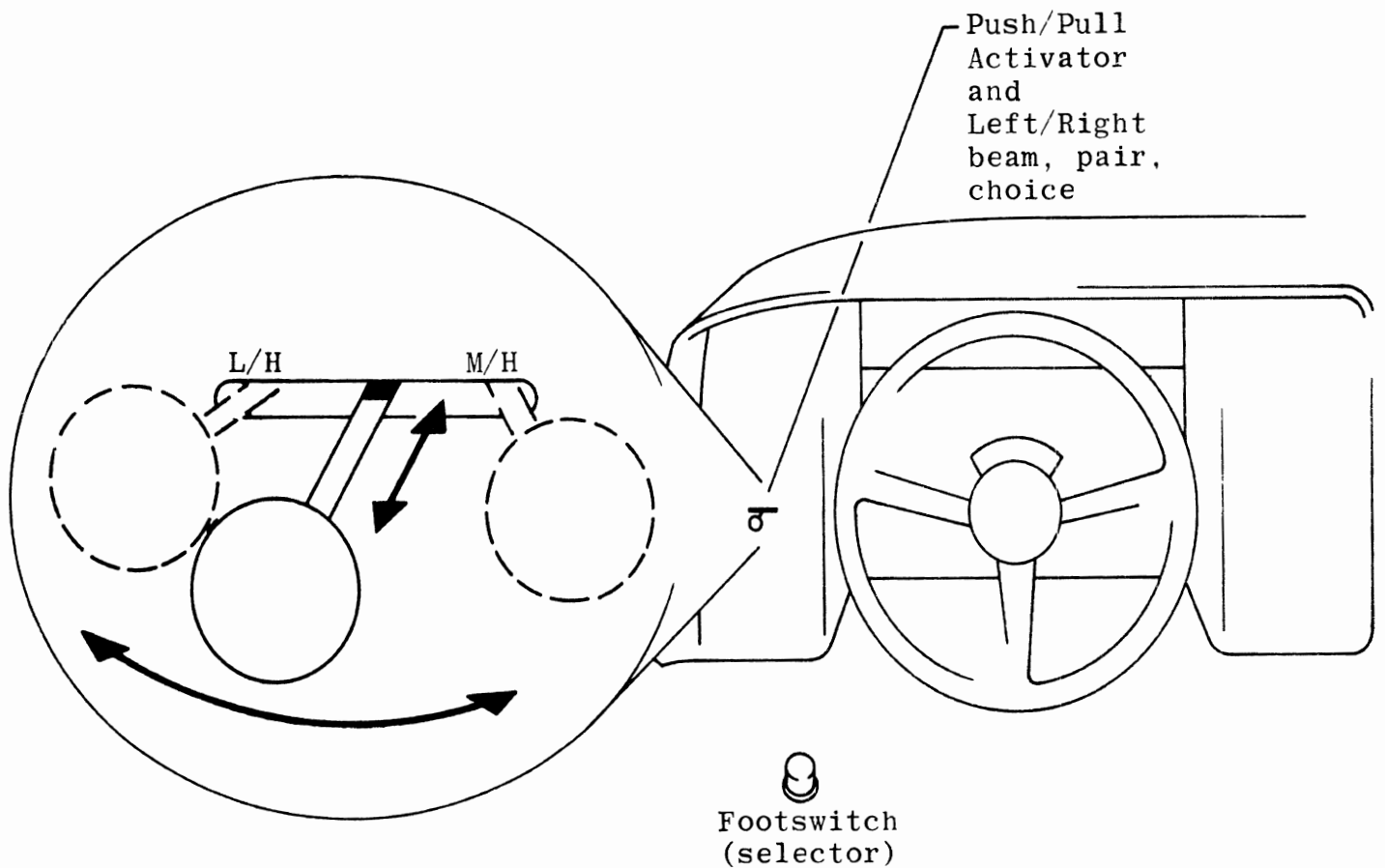


Figure 12. Three-beam switching configuration J.

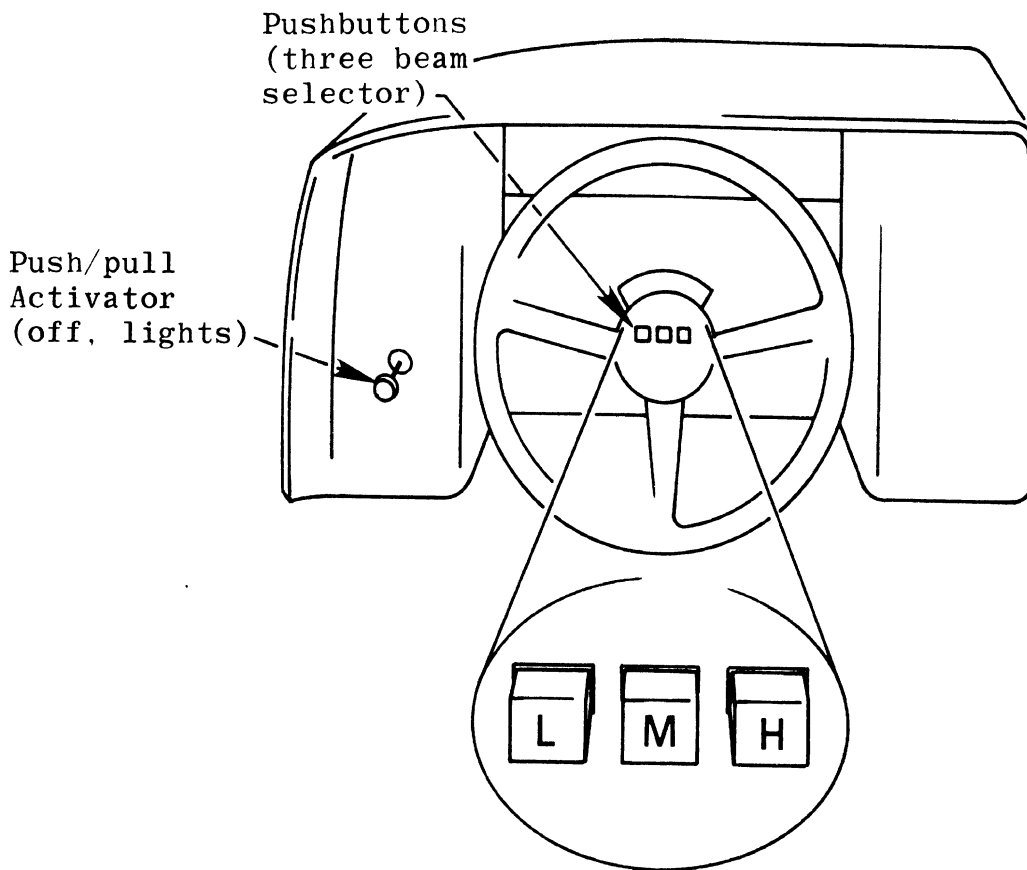


Figure 13. Three-beam switching configuration K.

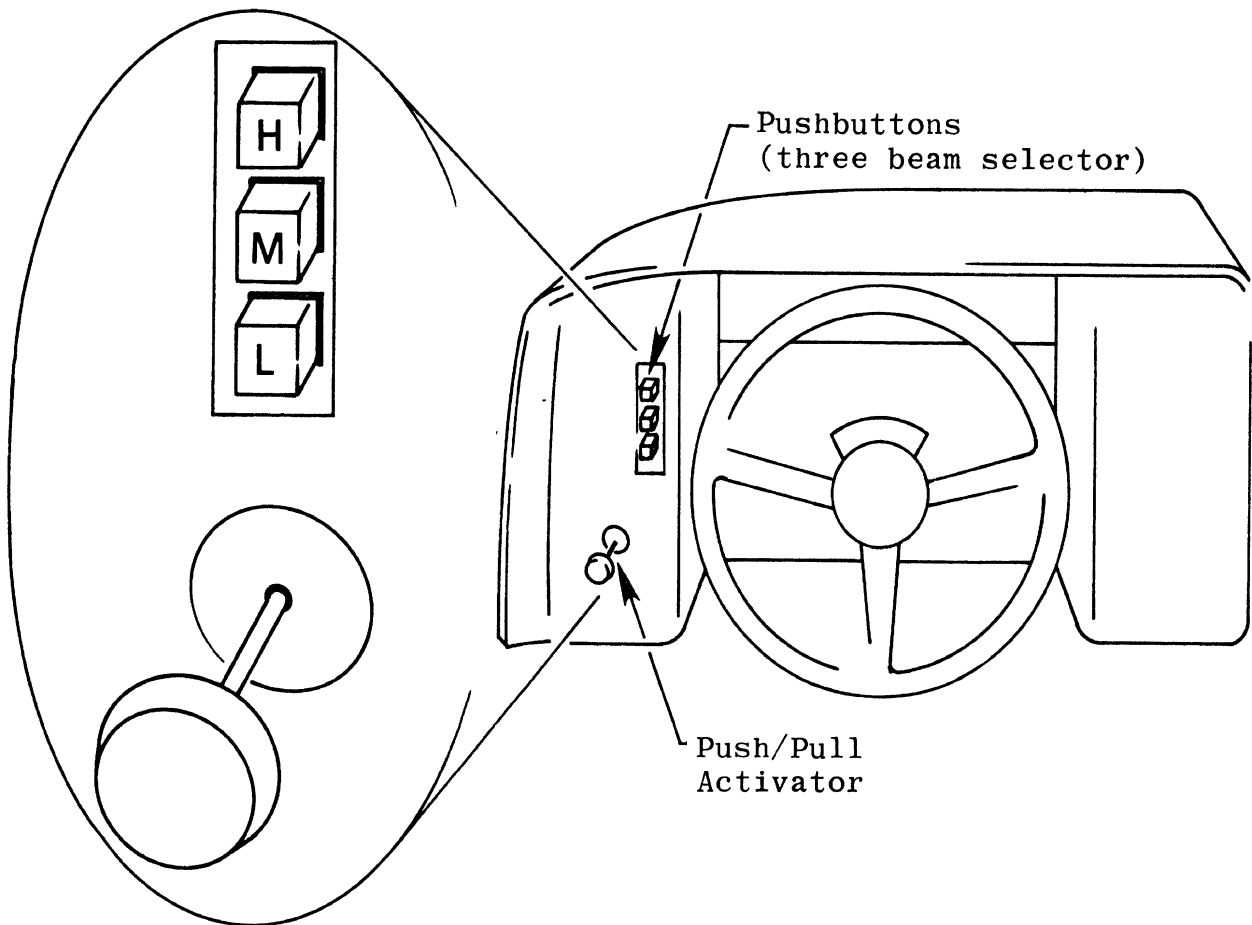
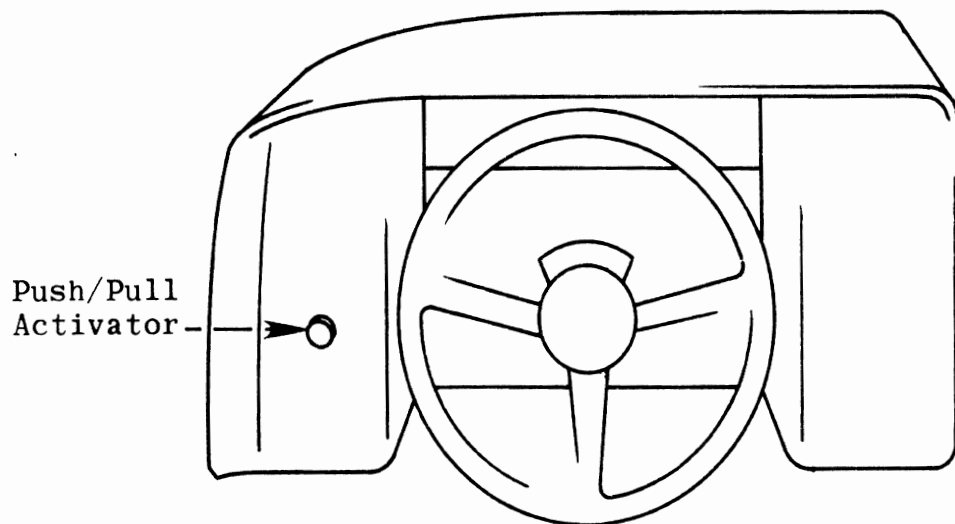


Figure 14. Three-beam switching configuration L.





⑧ Three Position Footswitch  
(three beam selector)

Figure 15. Three-beam switching configuration M.

