Before the need for fixed roadway lighting can be determined, driver visual needs must be identified. This paper first discusses driver performance on the levels of positional, situational, and navigational tasks and relates these levels to visual information needs. Field studies were conducted to refine the visual needs and to determine the pattern and frequency of needs on both controlled- and non-controlled-access facilities. The results of these field studies are presented. The responses of study teams consisting of four professionals and four lay drivers are outlined, and generalizations were drawn from their questionnaire responses.

FIXED ILLUMINATION AS A FUNCTION OF DRIVER NEEDS

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One of the most important characteristics of the twentieth century is the extent to which the automobile has provided mobility. The effect on society created by this mass mobility has yet to be fully understood. One effect, however, is apparent: Highway engineers are faced with the challenge of providing a safe and efficient system of streets and highways.

An analysis of highway accident statistics suggests that the highway engineering profession has not yet met this challenge for nighttime conditions. The night accident rate exceeds the day accident rate, and the fatality rate at night is two to three times that of the daytime fatality rate (23). A number of factors, including differences between the day and night driving population in terms of age, sex, amount of fatigue, and percentage of drinking drivers, contribute to the higher night rates.

It is generally concluded, however, that the absence of a good visual environment at night is one of the primary reasons for the higher rates. This conclusion is supported by research that showed decreases in night accidents and fatality rates after fixed roadway lighting was installed (6, 10, 23).

Fixed roadway lighting probably offers the most comprehensive means of correcting poor night visual environments. When properly applied, roadway lighting can provide quick, accurate, and comfortable seeing conditions for the night driver and can result in an overall improvement in highway accident statistics.

Although the state of the art in roadway lighting has progressed dramatically in the last few decades, shortcomings still exist. Roadway lighting design processes do not fully address themselves to the function that lighting is to serve. Currently there is no process for roadway lighting design that adequately relates to the visual needs of the driver. Lighting needs are specified in terms of traffic volumes, accident experience, and characteristics of abutting property, usually defined as commercial, industrial, or residential. These factors in turn serve as warranting conditions. Design criteria are specified in terms of lighting a roadway surface rather than in terms of providing an environment suitable to the driver. Priorities for lighting installations are normally based on accident experience, traffic volume, or political influences.

Ideally, the design process should be based on requirements of the visual environment. If roadway lighting is to improve the driver's visual environment, a method must be established for determining the driver's needs. When these conditions can be specified, it will be possible to rationally consider requirements for a suitable visual environment that can be provided by fixed roadway lighting. The requirements of the night driving visual environment must also be identified, and these, in turn, must be systematically studied so that design procedures can be developed that will assist the designer in meeting these requirements through roadway lighting.

The objectives of this paper are to present a rational relationship between the driving task and the visual roadway environment and to discuss roadway lighting as it relates to the visual roadway environment.

CONCEPTUAL FRAMEWORK

The conceptual framework on which the objectives are developed consists of visual information needs as related to the driving task and characteristics of traffic facilities that contribute to visual information needs.

Driving Task

Driver visual information needs are a direct function of what is required of the driver in performance of the driving task. Thus, to determine the requirements of a suitable visual environment requires a basic understanding of the driving task.

Previous research by King and Lunenfeld (16) identified three basic levels in the driving task: microperformance, situational, and macroperformance levels. During normal driving, all three are performed simultaneously. As the complexity of the driving task increases, there is a tendency to ignore the higher order levels (macroperformance then situational) and to concentrate on the lower order level. Woods and Rowan (26) restructured the concept to reflect traffic operations and provided the following definitions:

1. Positional level—routine steering or speed adjustments necessary to maintain a desired speed and to remain within the lane,
2. Situational level—change in speed, direction of travel, or position on the roadway required as a result of a change in the geometric, operational, or environmental situation, and
3. Navigational level—selecting and following a route from the origin to the destination of a trip.

These levels of driver performance can be ordered into a hierarchy that describes the organizational content of the driving task (16).

Visual Information Needs

Visual information needs associated with the driving task can be organized along the levels previously described. Although previous research has not made it possible to provide an inventory of visual information needs that take into account all possible trips and situations, types of needs associated with driver performance levels can be suggested.

Positional Information Needs

There are two major subtasks at the positional level, steering control and speed control, and elements of each are involved in all levels of the driving task.

The major information needs of steering control include vehicle response characteristics, vehicle location information, and all related changes. The following types of informational needs, as determined through driver-vehicle task analysis (16), are necessary for steering and speed control.

Steering Control

1. Lateral position with respect to the roadway so that minute steering corrections can be applied and a desired position can be maintained,
2. Spatial orientation with respect to the roadway immediately ahead,
3. Visual feedback of changes in position and orientation,
4. Changes in vehicle response when high demands are placed on the steering task (nonvisual information), and
5. Tactile and kinesthetic perception of accelerator, brake pedal, and vehicle response.

Speed Control

1. Visibility of the roadway at a sufficient distance ahead to maintain a safe speed,
2. Visibility of conditions on the roadway not consistent with the driver's expectancy, and
3. Integration of speed control with steering control requirements.

Situational Information Needs

Situational information indicates a need for a change in speed, direction of travel, or position on the roadway because of a change in the geometric, traffic, or environmental situation. Whereas the positional and associated information needs are very limited, situational information needs are as varied as the number and types of roadway and traffic situations encountered in driving. Information needs at this level include information on all aspects of the highway system, such as other vehicles, road geometrics, obstacles, and weather conditions.

Driver performance depends on the driver's perception of a situation and his ability to respond in an appropriate manner. Therefore, the driver must have a priori knowledge on which to base his control actions as well as an understanding of what the situation demands.

Subtasks at the situational performance level include car following, overtaking and passing, and other situational subtasks (16).

Car Following

In car following, the driver is constantly modifying his speed to maintain a safe gap between his car and the vehicle he is following. Thus, in this situation he is time sharing tracking with speed control activity. The minimal information needs are

1. Speed and changes in speed of the lead car,
2. Speed of the following car and relative distance between the driver and the lead vehicle, and
3. Environmental information.

Overtaking and Passing

Passing involves speed control as well as modifications in the basic tracking activity. In passing, the driver must know control information to maneuver his vehicle most safely. Minimum information necessary includes

1. How fast the lead car is traveling and the acceptance gap,
2. Environmental information, and
3. Information to provide for judgment, estimation, and feedback for maintaining

an area of safe travel relative to the vehicle and other elements of the highway system.

Other Situational Subtasks

Among the situational subtasks that may occur are avoidance of pedestrians or other objects and response to traffic signals, advisory signs, and other information carriers. In all cases, the important point in terms of information needs is that the driver must receive information so that he is able to identify a situation as it occurs.

These subtasks are closely related to roadway lighting. Minimal information needs are

1. Information to maintain a complete appreciation of all events that could affect safe travel,
2. Visual information concerning the relationship of the driver's vehicle to the roadway, to other vehicles, and to the environment, and
3. Information from the environment, a priori knowledge that will provide for appropriate steering and speed control responses, and feedback to indicate the adequacy of the response.

Navigational Information Needs

The navigational performance level takes into account the way in which the driver plans a trip and executes his trip plan. The navigational level consists of trip preparation and planning, which is usually a pretrip activity, and direction finding, which occurs in transit.

Trip Preparation and Planning

Drivers use various means to plan trips depending on experience and the nature of the trip. The means can be as formal as having the trip planned by a touring service or as simple as traveling a route used previously. However minimal the preparation is, it is unlikcly that a driver will attempt to reach a destination completely unprepared.

Direction Finding

In direction finding, the driver must find his destination in accordance with his trip plan and the directional information received in transit. He must thus share navigational subtasks with subtasks at the other driving levels. The information needs associated with direction finding are

1. In-trip visual information from guide and service signs and other formal information sources and
2. In-trip visual information regarding landmarks, the environment, and other informal information sources.

Descriptions of the driving task and associated information needs can be used to develop a driver information needs inventory of the night driving visual environment. This inventory should conform to the basic levels discussed previously. In addition, the descriptive informational needs should be structured around conditions or situations that characterize the street and highway system. Below are inventories developed as indicated by the field studies and categorized according to the situations and conditions encountered.

DEVELOPMENT OF VISUAL NEEDS INVENTORIES

Once the types of visual needs associated with the various levels of driver performance were established, field studies were conducted to refine these needs and to determine the pattern and frequency of needs on various types of facilities.

Although the field studies were concerned primarily with the requirements of the night driving environment, some emphasis was placed on the conditions warranting roadway lighting and priorities for the installation of roadway lighting. It is evident that, without visual task problems, roadway lighting is not warranted. Conversely, as visual task problems become apparent, so does the need for fixed illumination.

Studies were conducted in two areas at eight study sites. These eight sites included both controlled- and non-controlled-access facilities. The studies were conducted by interdisciplinary teams consisting of four professionals and four lay drivers.

The study technique was diagnostic study (20, 25, 26). Questionnaires and critique sessions were also used in the studies.

The results of the diagnostic studies are given in Tables 1 through 6. Tables 1 and 4 include all driver responses regardless of whether a serious problem existed.

The questionnaires, which were completed after each run, were tabulated to give general indications of driver attitudes and opinions on informational needs. The following generalizations on non-controlled-access facilities can be drawn from questionnaire responses.

1. The driver's position within a prescribed lane depends on (in descending order) lane lines, edge lines, curbs, position of other vehicles, post-mounted delineation, and roadside objects.
2. Changes in geometry force drivers to slow unexpectedly on unlighted sections, but not so much on lighted sections.
3. Illumination of facilities provides positive identification of roadway direction.
4. Good visibility of curbs and shoulders is necessary on lighted and unlighted facilities.
5. Intersections often have restricted visibility of traffic on that street, especially if unlighted.
6. Visibility of intersecting traffic in advance of the intersection is almost always important and usually very important.
7. The ranking (in descending order) of importance of informational signs is warning, regulatory, route, guide, and informal signs. Route and guide signs are more important for the nonlocal driver.
8. Extraneous lighting interferes with the driving task and more so on the unlighted facilities than on lighted facilities.
9. Roadside signs are considered more visible on lighted facilities than on unlighted facilities.
10. Delineation systems are more effective on lighted facilities than on unlighted facilities.
11. Glare from opposing headlights is more severe on unlighted facilities than on lighted facilities.
12. There were no strong objections to roadside advertising signs, and the informational importance of these devices was considered unimportant.
13. Pedestrians are not expected at midblock, but illumination of pedestrian crosswalks was considered a necessary prerequisite for safety.

Similar generalizations can be drawn from the questionnaires on the freeway sites.

1. The driver's position within a prescribed lane depends on (in descending order) lane lines, edge lines, position of other vehicles, post-mounted delineators, and objects along the roadside.
2. Geometric conditions cause drivers to slow unexpectedly, especially on unlighted freeway sections.
3. Complete loss of roadway direction is seldom encountered on freeways.

Table 1. Summary of responses on the non-controlled-access study site.

Type of Information	Unlighted			Lighted		
	Number of Responses	Lighting Would Be Helpful		Number of Responses	More Light Would Be Helpful	
		Number	Percent		Number	Percent
Positional	59	3	5.1	27	0	0
Situational	303	112	37.0	211	15	5.7
Navigational	13	2	9.2	2	0	0

Table 2. Significant visual task problems on unlighted, non-controlled-access facilities.

Visual Task Problem	Number of Occurrences	Percentage of Total	Causative Factor			
			Geometry	Operations	Environment	General Visibility
Roadway	33	25.8	11	2	16	5
Intersections	33	25.8	7	11	10	6
Channelization	11	8.6	1	7		3
Lane markings	11	8.6		8	1	2
Roadside and roadside objects	9	7.0			5	4
Curbs	8	6.3		6	2	1
Access drives	7	5.5		1	4	2
Pedestrians	4	3.1	3	1	1	
Vehicles	4	3.1	1	2	2	
Signs	4	3.1				4
Signals	2	1.6			2	
General visibility	2	1.6	—	1	1	—
Total	128	100	23	39	44	27
Percent			17.3	29.3	33.1	20.3

Table 3. Significant visual task problems on lighted, non-controlled-access facilities.

Visual Task Problem	Number of Occurrences	Percentage of Total	Causative Factor			
			Geometry	Operations	Environment	General Visibility
Roadway	8	19.0	3	1	2	2
Nonuniform lighting	6	14.3				6
Distraction	5	11.9			5	
Luminaire glare	5	11.9				5
Signal lights	4	9.5	1		1	2
Light to dark transition	3	7.1		1		2
Loss of visibility	3	7.1			2	1
Roadside and roadside objects	3	7.1	1			2
Pavement edge	1	2.4				1
Lane markings	1	2.4				1
Signs	1	2.4				1
Glare	1	2.4			1	
Dark to light transition	1	2.4	—	—	—	1
Total	42	100	5	2	11	24
Percent			11.9	4.8	26.2	57.1

Table 4. Summary of responses on the freeway study sites.

Type of Information	Unlighted			Lighted		
	Number of Responses	Lighting Would Be Helpful		Number of Responses	More Light Would Be Helpful	
		Number	Percent		Number	Percent
Positional	49	5	10.2	26	0	0
Situational	280	104	37.1	74	12	16.2
Navigational	37	19	51.4	6	2	3.3

Table 5. Significant visual task problems on unlighted freeways.

Visual Task Problem	Number of Occurrences	Percentage of Total	Causative Factor			
			Geometry	Operations	Environment	General Visibility
Roadway	36	26.1	16	12	8	3
Signs	18	13.0	4	3	2	9
Ramp entrances	15	10.9	7	4		6
Ramp exits	13	9.4	10	2	1	1
Merges	12	8.7	5	4		3
Intersections	8	5.8	4	1	1	3
Curbs	7	5.1	1	5		1
Roadside and roadside objects	7	5.1		1		6
Lane markings	4	2.9		1	1	2
On-ramps	4	2.9	2	2		
Off-ramps	3	2.2	2	1		
Vehicles	3	2.2	2	3		
Delineation	2	1.4				2
Light transition	2	1.4				2
Channelization	2	1.4	2			
Roadway objects	1	0.7				1
Glare	1	0.7				1
Total	138	100	55	39	13	40
Percent			37.4	26.5	8.8	27.2

Table 6. Significant visual task problems on lighted freeways.

Visual Task Problem	Number of Occurrences	Percentage of Total	Causative Factor			
			Geometry	Operations	Environment	General Visibility
Glare	4	14.3	1	1	2	2
Ramp exits	4	14.3	4			
Merges	3	10.7		1		2
Signs	2	7.1	1			1
Roadside and roadside objects	2	7.1				2
Pavement edge	2	7.1				2
Roadway	2	7.1	2			
Ramp entrance	2	7.1	2			
Distraction	1	3.6			1	
Light to dark transition	1	3.6				1
Lane markings	1	3.6				1
Off-ramps	1	3.6	1			
On-ramps	1	3.6	1			1
Luminaire glare	1	3.6				1
Nonuniform lighting	1	3.6				1
Total	28	100	12	2	3	14
Percent			38.8	6.5	9.7	45.2

Table 7. Characteristics of traffic facilities that affect visual information needs.

Access and Facility	Characteristic		
	Geometric	Operational	Environmental
Non-controlled-access, highway	Number of lanes, lane width, median openings, curb cuts, curves, grades, sight distance, parking lanes	Signals, left turn signals and lanes, median width, operating speed, pedestrian traffic	Development, type of development, development setback, adjacent lighting, raised curb medians
Non-controlled-access, intersection	Number of legs, approach lane width, channelization, approach sight distance, grades on approach, curvature on approach, parking lanes	Operating speed on approach, type of control, channelization, level of service, pedestrian traffic	Development, type of development, adjacent lighting
Controlled-access, highway	Number of lanes, lane width, median width, shoulders, slopes, curves, grades, interchanges	Level of service	Development, development setback
Controlled-access, interchanges	Ramp types, channelization, frontage roads, lane width, median width, number of freeway lanes, main lane curves, grades, sight distance	Level of service	Development, development setback, crossroad lighting, freeway lighting

4. Good visibility of shoulders is an important prerequisite for safe driving.
5. Good visibility of gore areas of exit ramps is always important regardless of whether an exit is to be made.
6. Ability to see the merge point of an entrance ramp with the freeway is always important.
7. Detection of changes in exit ramp alignment is important before the exit maneuver is begun.
8. Changes in the number of traffic lanes affect drivers, especially on unlighted freeways.
9. Definition of the median edge is important, especially to a driver traveling in the adjacent lane.
10. The ranking (in descending order) of importance of various informational signs is warning, regulatory, guide, route, and informal signs. Guide and route signs are more important to the nonlocal driver.
11. Lighting of adjacent developments interferes with vision less on lighted freeway sections than unlighted freeway sections.
12. Most overhead signs are effective from the visibility standpoint as are roadside signs. They are slightly more effective on lighted freeways than on unlighted freeways.
13. Headlights of opposing traffic create visual problems on unlighted freeways and to some extent on poorly lighted freeways. Headlight glare is least noticeable in median lighting situations.
14. Roadside advertising signs are not especially excessive and their informational value is relatively unimportant.
15. Entrances to on-ramps are seldom visible at an adequate distance on unlighted freeways. It is always important to see the entrance, regardless of whether an entrance is to be made.
16. Exits for off-ramps are seldom visible at an adequate distance on unlighted freeways and sometimes on lighted freeways. It is always important to see the exit, regardless of whether an exit is to be made.

The results of the critique sessions are summarized in the subsequent paragraphs.

The first consensus reached by the study teams involved the necessity of maintaining positional information at all times. Information on lane lines, edge lines, and curb delineation was considered to be the most critical and most necessary information because it held the key to other informational levels. All other tasks at the situational and navigational levels depended on the sufficiency of these visual inputs. The subjects insisted that situational and navigational tasks could be accomplished most effectively when these items were readily available. During the driving runs, it was observed in too many cases that the drivers attended to positional tasks at the sacrifice of the situational and navigational levels. This was due primarily to worn and faded lane lines, absence of edge lines, unpainted curbs, and little contrast between pavement edges and shoulders.

Both study teams also agreed on geometrically induced visual task problems. Even in the interview sessions, the study teams supported the hypothesis that a view of the roadway surface is important at all times. Excessive geometric changes producing restricted longitudinal views of the roadway were considered among the most critical and frequently occurring visual problems.

The study teams also supported the importance of environmental development with regard to informational needs. A strong emphasis was placed on the fact that some environmental lighting has a detrimental effect on performance of the driving task. There was some disagreement, however, on the characteristics of environmental lighting that made it detrimental. This disagreement obviously stemmed from the fact that on several occasions environmental lighting actually assisted in determining roadway direction on unlighted arterials and directed light onto the roadway surface. A final agreement was reached that environmental lighting is detrimental unless a considerable intensity of light actually reaches the pavement surface and unless such sources of light are not in themselves distracting or glaring.

Traffic operations were also considered major determinants to visual information needs. Higher speeds and higher volumes can produce definite visual task problems. First of all, opposing headlights introduce periods of time in which vision is virtually obliterated, and the problem increases as the number of opposing vehicles increases. Lateral separation of vehicles and fixed lighting, especially median-mounted, were considered the best solution to the problems. It was also agreed that accomplishing all driving tasks became more difficult as volumes and speeds increased, mainly because of the competition between the various informational needs.

The final task of the study teams was to develop listings summarizing

1. Visual needs that could be met by fixed roadway lighting,
2. Traffic facility characteristics that affect visual information needs, and
3. Desirable attributes of roadway lighting systems.

On non-controlled-access facilities, fixed roadway lighting can provide information on roadway geometry, roadway surface, roadway objects, roadway edge, roadway markings, signs, signals, delineation, intersection location, channelization outline, access driveways, shoulders, roadside objects, curb locations, vehicles on the facility, pedestrians, pedestrian crosswalks, and sidewalks.

On controlled-access facilities, fixed roadway lighting can provide visual information on roadway geometry, roadway surface, roadway objects, roadway edge, roadway markings, signs, signals on crossroads, delineation, intersection location, channelization outline, curb locations, shoulders, roadside objects, vehicles on the facility, vehicles on interchanging facilities, ramp entrances, ramp exits, merge points, and geometry of on-ramps and off-ramps.

Table 7 gives geometric, operational, and environmental characteristics of traffic facilities that affect visual information needs.

On non-controlled-access facilities, roadway lighting systems should provide uniform lighting on pavement surface, infrequent spacings to reduce glare, high mounting heights to reduce glare, median location to reduce headlight glare, median location to light areas adjacent to roadway, gradual transitions from light to dark areas, and gradual transitions from dark to light areas. On controlled-access facilities, roadway lighting should provide uniform lighting on pavement surface, infrequent spacings to reduce glare, high mounting heights to reduce glare, median location to reduce headlight glare, median location to light areas adjacent to roadway, high-mast lighting in interchange areas, gradual transitions from light to dark areas, and gradual transitions from dark to light areas.

DESIGN PROCEDURE

The design procedure for effective roadway lighting must be responsive to information needs of night drivers. The procedure must identify the information needs that are to be satisfied by roadway lighting, quantify the needs for warranting conditions and design guidelines, and provide a rational method for setting cost-effective priorities. The design procedure should be responsive to these needs.

The design procedure comprises the following elements:

1. Informational needs that are to be satisfied by fixed roadway lighting (requirements for the suitable visual environment),
2. Justification for the lighting (warranting conditions),
3. Design criteria for lighting (providing for the informational needs),
4. Realization of design criteria (illumination design), and
5. Cost-effectiveness priority determination (which lighting designs are most effective and which should be installed first).

Based on these elements, it should be possible to develop a design procedure that is responsive to the goals of lighting and, at the same time, that is compatible with almost any design technique (i.e., illuminance design, luminance design). Suggested procedures have been recommended (27).

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