# Communicative Aspects in Highway Design

Jack E. Leisch, Jack E. Leisch and Associates, Evanston, Illinois

**The operation of a vehicle is a complex process for the driver. To ease the task and to improve operations and safety, it is necessary to incorporate communicative aspects in highway design, i.e., to make clear to the driver the messages conveyed by the facility. Numerous geometric and control features that have been formulated in response to human-factors inputs are presented in this paper. Particular attention is directed to various features of design. Among these are alignment, sight distance and cross-sectional features, and operational uniformity, route continuity, and marking and signing. The suggested guidelines permit immediate application and are a starting point for improving design criteria on a larger scale. They could significantly improve the operational efficiency and safety on both existing and new facilities, but the designer's input—his or her philosophy and skill—must play an important role in meeting the objective of achieving optimum design.**

Operating on today's highways is a complex process that involves the driver in many intricate and overlapping tasks of sensory detection, perception, analysis, and decision, which must be followed by responses of vehicle control, guidance, and navigation. The present highway and traffic environment is not fully adapted to the makeup of the driver. Yet, there has been some encouraging progress in highway design in considering the combined effects of driver, vehicle, and roadway.

Much attention has been directed to the study of human factors during the past several years, but extensive application of these factors has not yet taken place effectively. The highway and traffic engineer has not always taken advantage of this relatively new field, sometimes waiting for further research, but more often hesitating because of the natural tendency to maintain the status quo. However, while the field of human factors as related to the driver does need more research, there is already considerable knowledge that could be used in the design of highway geometrics and traffic-control devices.

Alexander and Lunenfeld (1) have developed a systematic approach and a procedure to identify a driver-performance level for what they term positive guidance—the selection of an appropriate and safe speed and path on the highway. (Their guidelines are primarily oriented toward immediate cost-effective improvements of existing trouble spots, but the principles apply equally to the rehabilitation of whole facilities and the design of new highways.) This paper presents specific design measures that respond to positive guidance and provide communicative features and is intended to complement their paper. Its broad objective is to make the highway, through design and control devices, responsive to the characteristics and needs of drivers so that they can comprehend and interpret the facility with comfort, efficiency, and safety.

Driver characteristics, such as height of eye, perception-reaction time, deceleration, lane-changing behavior, maintenance of headway between vehicles, and other aspects of operational behavior, have been used for many years as inputs to highway design (2). This has given guidance in the establishment of appropriate geometric standards, but further design improvements will require a better in-depth understanding of driver behavior and the reasons for it. Not only the physiological characteristics of the driver, but also his or her psychological and emotional makeup has a significant role in how to design a highway and control its operation.

The aspect of the human element in design requires more than the consideration of driver behavior and characteristics. It also involves the designer and his or her philosophy and skill. The designer applies standards, chooses the minimum or desirable values, considers the human factors that relate to the driver, and develops the composition of the facility in three dimensions. The designer's philosophy, attitude, awareness, and concern, as well as capability, are significant in determining the operational features of the highway. The concern for the well-being of the driver, the designer's (and the designing agency's) compassion for him or her, can dramatically affect the quality of the design. Thus, the effective use of the human element provides an output of proper, efficient, and safe design. This paper first explores the various inputs of driver behavior and characteristics and then presents a series of key features as design outputs that are either not covered by present standards or are used partially or in a limited way (3, 11).

## HUMAN-FACTORS INPUTS

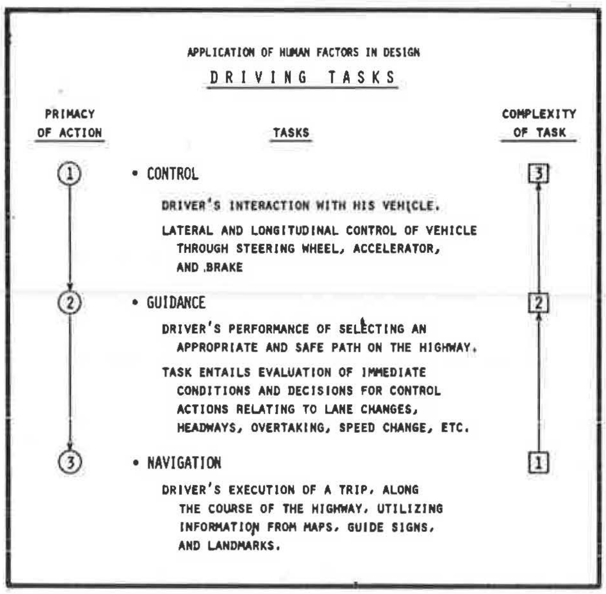
The reason for using human factors is to design facilities that operate more efficiently and safely. There is an immediate need to upgrade or supplement those elements of existing standards that do not respond to the more in-depth knowledge of driver behavior that is now available.

The design objectives, as outlined below, are threefold:

1. To compensate in the design for any momentary or temporary impairment of the driver due to his or her physiological and psychological state (anxiety, confusion, frustration, fatigue, monotony, or effects of alcohol, drugs, or illness);
2. To incorporate design features on the facility that meet driver expectations; and
3. To design the highway, geometrically and in coordination with control devices, so as to reduce and simplify the driving task.

In applying driver-behavior factors to performance, the total driving task should be considered as consisting of three subtasks—control, guidance, and navigation—as shown in Figure 1 (1, 5, 6). These subtasks frequently are not performed independently. At any given time, the driver is confronted with a multitude of information from a variety of sources. He or she must sift through this information, determine its relative importance, interpret it, decide on a course of action, and take that action within a limited time period. Under these circumstances the driver may experience anxiety, confusion, and harassment that can impair performance and affect safety. The driver will perform most efficiently and best if there is only one task at a time. Thus, the separation of the three types of tasks along

Figure 1. Driving tasks to be considered in design.




the course of the highway is a major objective in design. The designer requires knowledge of the performance levels of the driving tasks and the complexity and priority of action of each.

Another important design objective is that of meeting driver expectations. A driver develops a set of expectations of what the roadway will be like through experience (4). Thus, the highway conveys a certain message that he or she must interpret correctly. A list of some of the more common expectancies relating to through driving and turning maneuvers is outlined below.

1. The number of through lanes approaching and leaving a given area will be the same.
2. At a division point, the most important route will have the most lanes.
3. The most important route will be the most direct.
4. After the driver has entered a curve, there will be no speed reduction on it.
5. A speed reduction will be required to safely negotiate a connecting roadway between two major facilities.
6. All freeway exits will be on the right.
7. Left turns onto an intersecting roadway from an arterial street will be made from the left-hand lane.
8. To go to the right on an intersecting freeway, a driver will turn right in advance of the interchange structure.
9. Right turns are made from the right-hand lane: The driver will move to the right-hand lane and then continue to the desired intersection or exit point.
10. What appears to be a regular lane on a highway will be continuous and not be dropped.

Expectancies occur in all three parts of the driving task, and the configuration of the highway and its various elements should allow the driver to visually interpret the highway conditions and to accurately predict the maneuver, which should be reasonably consistent with what he or she normally would anticipate.

The third significant design objective is the recognition of and compensation for driver inherent characteristics (8). Drivers as a group have certain tendencies and desires, some of which are listed below.

1. Drivers desire and tend to travel at relatively high speeds, upward of 80 km/h (50 mph), where deterrents are few and free-flow characteristics are present.
2. Drivers entering and leaving curved roadways do so by negotiating a transitional path.
3. Drivers exiting and entering high-speed highways, via a turning roadway or ramp, do so by a direct and gradually diverging or merging maneuver.
4. Drivers traveling along a variable alignment tend to speed-up when the quality of the alignment improves.
5. Drivers tend to overdrive crest vertical curves on favorable horizontal alignments.
6. Drivers tend to overdrive turning roadways.
7. Drivers lose their sense of speed on long, sustained driving and tend to overdrive situations that require speed reductions.
8. Drivers orient themselves and choose their paths by following delineating features on or along the side of the highway.

Here, too, driver misjudgment, anxiety, frustration, fatigue, and monotony can be mitigated by appropriate design. Where the design fits the manner in which the driver operates—his or her inherent behavior and characteristics—there is a definite improvement in operational efficiency and safety.

By compensating for probable driver impairments, meeting driver expectations, and accounting for driver inherent characteristics in the design process, the driving task can be greatly reduced. However, there are a number of measures that are not necessarily covered by the above considerations that can also enhance driver-response capabilities and improve communicative operating conditions. The use of a three-dimensional approach considered dynamically from the driver's view can be the means for simplifying the operations. A large part of the answer to reducing the driver's task is simply to make it simple.

## DESIGN OUTPUTS

When the human-factors inputs are coupled with a sensitivity on the part of the designer to achieve optimum operating conditions within the available resources and constraints, it is possible to upgrade the geometric features and the informational system of a highway much beyond what past practices have produced. The design features and guidelines given here are a series of measures and design elements that are derived largely on the basis of human-factors requirements. The list is not all-inclusive, but does cover many of the major design areas and is directed toward minimizing operational system failures. Most of the items are related to the visual or the communicative aspects of the highway, the messages conveyed by the facility, which allow the driver to relate to it with the minimum need to process information.

### Design-Speed Application

A design speed is selected and used in an attempt to achieve a uniform design, primarily through correlation of the various features and elements of the highway that control or influence vehicle operation (2). The application of design speed should include those human-factors aspects that provide consistency in design.

The design-speed concept was well established during the 1940s and has enhanced design significantly, although its application under current conditions has produced some problems. The primary difficulty occurs on intermediate and low design-speed facilities on which variations in operating speed caused by changes in alignment cause inconsistent speeds. This inconsistency and its associated hazard are caused by the tendency of drivers to increase speed on flatter portions of the alignment, which then requires them to decrease speed on approaching sharper or controlling curves. Another problem is that the design speed is not always compatible with the driver's expectation and judgment.

Figure 2. Alignment coordination to more accurately convey highway form.

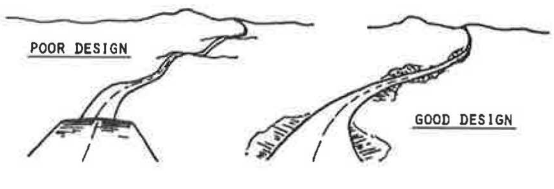



Figure 3. Balance and compatibility of horizontal alignment and vertical profile.

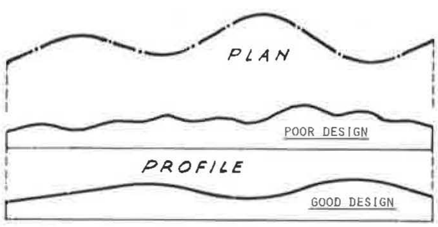



Figure 4. Preferred horizontal alignment.

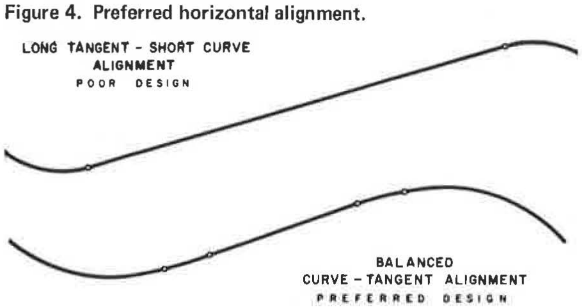



Figure 5. General guide for coordination of horizontal and vertical alignments.

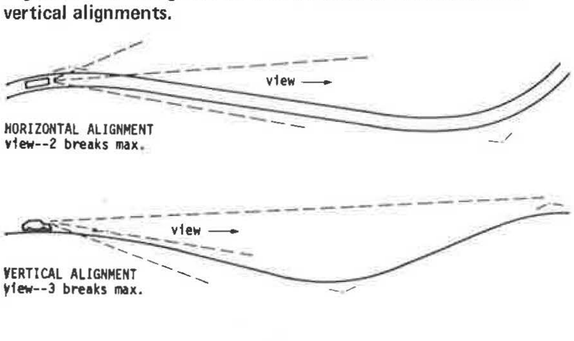
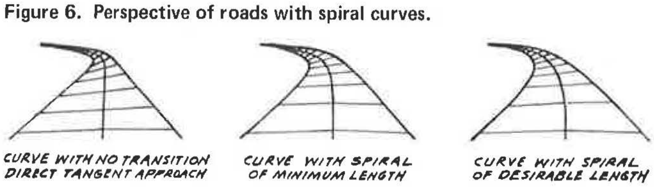



Figure 6. Perspective of roads with spiral curves.




Minimizing these two problems in the present use of the design-speed concept is an important objective. An updated concept and application of design speed that attempts to reach this goal by the use of the 15-km/h (10-mph) rule as a design principle is given by Leisch and Leisch in the preceding paper.

## Alignment Design and Coordination

Coordinating the horizontal and the vertical alignments of a highway not only enhances its aesthetic quality, as shown in Figure 2, but also provides a positive means to more accurately present the shape and character of the highway to the driver proceeding along it. The smooth-flowing quality and avoidance of sight loss (the disappearing and reappearing of the road) are desirable goals.

A driver's foreshortened view of the roadway ahead gives him or her specific information on conditions that will soon be experienced. If a driver becomes apprehensive about an apparent condition seen some distance ahead, but then finds on arrival at the spot that the apprehensions were unnecessary, he or she must conclude that the visual information received previously was false. Such experience repeated many times at different places breaks down the visual communication from the highway to the driver, who then tends to lose his or her ability to judge, to orient, or to make valid choices. Thus, the messages conveyed by the facility must be consistent with its operational characteristics. This requires a design that provides a semblance of visual accuracy to the real character and condition of the roadway as it is viewed by the driver (8).

Although ideal coordination cannot always be achieved because of other controlling features, a degree of coordination usually can be achieved. The success in this depends largely on how this feature is considered, tested, and evaluated during the location stages of the design process, although once the location is selected, further adjustments and refinements to improve coordination can be made during the functional and preliminary design stages.

The proper combination of the horizontal alignment and the vertical profile, to present an accurate picture and improve driver confidence, can be made by following several general principles. The horizontal and vertical alignments should balance the horizontal and vertical portions of curves and tangents of somewhat similar length, as shown in Figure 3. Moreover, the vertices of the horizontal and vertical curve elements should be in general proximity.

Another feature to be considered is that of the relative proportions of tangent and curve elements on the horizontal alignment. A long tangent and short curve arrangement should be avoided: Figure 4 illustrates a treatment that produces more uniform operation and better aesthetics. To reduce the probability of misleading a driver who is negotiating a curved alignment, a sharp curve should not be preceded by a long flat curve unless there is an effective transition treatment. Individual elements of the vertical alignment also should maintain a balance; however, long tangent grades are often appropriate, if they do not reduce speed unduly and if the vertical curves do not obstruct the view of subsequent horizontal curves.

The use of these principles and special alignment models and computer graphics can produce reasonably good results. An additional general guide that can be used to coordinate the alignment and the profile, visualizing the whole in three dimensions, is given in the Federal Highway Administration seminar notes (8), where it is suggested that the likely (although not necessarily) maximum number of breaks or changes in the course of the longitudinal line should be no more than two horizontally or three vertically. This guideline is illustrated in Figure 5.

Accidents on curved portions of roads and skidding on curves have led to a further examination of curve-design practices. The loss of friction on roadway pavement surfaces with time is one problem, and the centripetal acceleration and balance of forces as the driver proceeds into and out of a circular curve are another. The manner in which superelevation is developed preceding a circular curve and the speed of approach by the driver, which is sometimes excessive, may combine with the substandard frictional quality of the pavement (particularly when it is wet) to produce an accident-prone situation. Steering adjustments on entering the curve, particularly when combined with braking, may cause an unbalance of forces that results in a horizonal skid.

Because a driver naturally steers a transitional path on entering or leaving a circular curve, a transition or spiral curve is desirable in combination with the circular curve, to fit the driver's inherent operational behavior. The spiral further acts as the element through which superelevation is developed. Thus, the combination of these two features allows the driver to operate gradually with minimum steering effort and maximum comfort, which reduces the probability of skidding. The transitional design also allows the driver to reduce speed smoothly over the length of the spiral should his or her approach be too fast for the circular curve.

The use of spirals improves the driver's operation and comfort, and makes steering easier and more accurate. Spirals also produce a smoother appearing transition that is more accurate to the character of the alignment and to the performance that the driver expects to experience. Perspective sketches of approach views to curves with and without spirals are shown in Figure 6.

Operational experience and engineering judgment clearly indicate the need for the use of spirals. However, the spiral lengths currently used are apparently too short. These lengths should be increased from the 60 to 90 m (200 to 300 ft) used at present to 120 to 180 m (400 to 600 ft) to take advantage of the transitional path provided for comfort, safety, and appearance. Recommended minimum lengths of spirals for sharp (minimum or near-minimum radii for the indicated design speed, i.e., the lowest 30 percent of radii) and flat (maximum radii on which spirals are first introduced at indicated design speed, i.e., highest 30 percent of radii) curves in relation to design speed are given below (1 m = 3.3 ft; 1 km/h = 0.62 mph).

| Highway Design Speed (km/h) | Minimum Spiral Length (m) | |
|---|---|---|
| | Sharp Curve | Flat Curve |
| 50 | 60 | 45 |
| 65 | 90 | 60 |
| 80 | 120 | 75 |
| 95 | 150 | 90 |
| 110 | 180 | 120 |

## Sight Distance

Sight distance—the ability of the driver to see the road ahead—is probably the most important individual design feature from the standpoint of safety. Recently the American Association of State Highway and Transportation Officials (AASHTO) issued a new policy on stopping sight distances that provides larger values (as more desirable criteria) for design (2). These are defined as the desirable minimum required continuously along the highway and are shown below (1 m = 3.3 ft; 1 km/h = 0.62 mph).

| Design Speed (km/h) | Sight Distance (m) | | |
|---|---|---|---|
| | Stopping | Anticipatory | Passing |
| 50 | 60 | 180 | 340 |
| 65 | 90 | 250 | 460 |
| 80 | 160 | 340 | 550 |
| 95 | 200 | 460 | 630 |
| 110 | 260 | 600 | 750 |

The complexity of operating on modern highways and the need to frequently process information on them require even longer sight distances at certain locations. This distance, the anticipatory sight distance, is particularly important in areas of potential hazard and at points requiring driver decisions (8). Such areas or points may involve intersections, interchange exits, lane drops, railroad grade crossings, drawbridges, toll-collection booths, or zones of design-speed reduction. This distance may also be referred to as the decision sight distance and is defined as the distance at which a driver can detect a hazard signal in an environment of visual clutter, recognize the threat of the potential hazard, select an appropriate speed and path, and perform the required maneuver safely and efficiently (1).

The anticipatory sight distance is not yet part of the AASHTO design criteria, although the concept of longer sight distances under such circumstances is certainly implied. Preliminary investigations have indicated that the distances are approximately 2.5 to 3 times the stopping sight distances, i.e., on highways having higher design speeds they are in the range of 460 to 750 m (1500 to 2500 ft). Their values, measured to the roadway surface, and their relations to other forms of sight distance requirements are shown above. A significant implication of the anticipatory sight distance is that these extra long distances would be provided only occasionally as needed for particular conditions. They would be provided during the location study stage and would be designed in a natural manner wherever feasible so as not to require undue cost; i.e., frequently the feature itself would be positioned where the extra sight distance was already available.

Longer stopping sight distances may be required in the operation of large trucks. There are circumstances where the increased height of eye within the truck has no advantage, i.e., on the inside of a horizontal curve with near-vertical obstruction, on steep downgrades, and particularly on combinations of the two. Stopping distances for large, loaded trucks may vary from 1.5 to 2 times those needed for passenger cars. The suggested stopping sight distances for trucks, measured from an eye height of 1.8 m (6 ft) to 15 cm (0.5 ft) above the roadway, are shown below (1 m = 3.3 ft; 1 km/h = 0.62 mph).

| Design Speed (km/h) | Stopping Sight Distance (m) | Design Speed (km/h) | Stopping Sight Distance (m) |
|---|---|---|---|
| 50 | 90 | 95 | 270 |
| 65 | 160 | 110 | 360 |
| 80 | 180 | | |

## Cross-Sectional Delineation

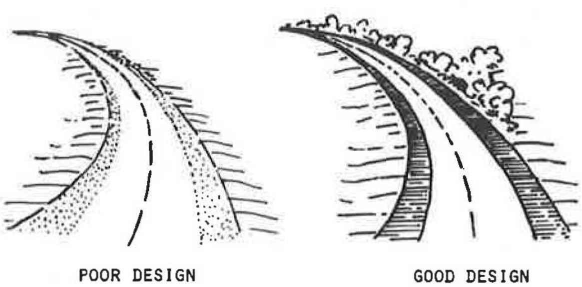
A distinctive cross section that communicates the character of the roadway clearly and accurately to the driver will give him or her valuable information about the facility ahead. This information can be transmitted to the driver most effectively by delineating the edges of the travelway and all of the significant elements in the cross section.

Delineation and contrast can be effected by the use of materials with different textures and colors on the various elements, by the application of pavement striping, and by variation in cross-slope surfaces, and is sometimes supplemented by outer curbing and delineators or other guide devices. Variations in roadside grading and planting can also assist in driver orientation and transmit the message conveyed by the facility. This is illustrated in Figure 7.

Delineation can clarify the three-dimensional form of the roadway as it unfolds before the driver and help him or her to gauge the rate of travel and the directional position. Variable landscape treatments and changing the form of the roadside grading to present a different appearance at each point along the roadway assist the driver in judging speed, position, and change of direction as he or she progresses along the facility. Such treatments provide the driver with a sense of the appropriate speed, introduce interest without distraction, and on long, sustained trips, tend to obviate drowsiness and monotony.

With respect to construction and maintenance practices, delineation may be a troublesome feature that adds to the cost of the facility. However, such cross-sectional refinement clarifies the three-dimensional form along the highway for the driver, orients him or her, and eases the driving task. Thus, the message conveyed by the facility can be expressed effectively by a properly executed cross-sectional delineation.

**Figure 7. Delineation features for cross-section design.**




## Operational Uniformity and Interchange Design

Freeway and crossroad interactions depend on the configuration and arrangement of interchanges. In general, interchanges along most freeways have an inconsistent operational pattern—some have two exits from each freeway approach, some have one exit, some have left-hand ramps, and some have exits in advance of and some beyond the crossroad structure. This lack of uniformity creates an inconsistent pattern of signs and may cause undue lane changing and produce erratic maneuvers.

To increase efficiency and safety, interchanges should be patterned to provide an operational uniformity to meet driver expectancy (9). The arrangement of exits and entrances along a freeway or high-quality highway should be consistent, and the pattern of directional signing should be uniform.

Operational uniformity can be achieved by providing, at each interchange along the freeway route, a single

**Table 1. Recommended values for spacing of entrance and exit ramps.**

| Configuration | L[a] (m) Desirable | Adequate | Absolute Minimum |
|---|---|---|---|
| Entrance-entrance or exit-exit | | | |
| Freeway | 450 | 350 | 300 |
| Collector-distributor road or freeway distributor | 350 | 300 | 250 |
| Exit-entrance | | | |
| Freeway | 225 | 175 | 150 |
| Collector-distributor road or freeway distributor | 175 | 150 | 125 |
| Turning roadways | | | |
| System interchange | 350 | 300 | 250 |
| Service interchange | 300 | 250 | 200 |
| Entrance-exit (weaving) | | | |
| System-to-service interchange | | | |
| Freeway | 900 | 750 | 600 |
| Collector-distributor road or freeway distributor | 600 | 550 | 450 |
| Service-to-service interchange | | | |
| Freeway | 600 | 550 | 450 |
| Collector-distributor road or freeway distributor | 450 | 350 | 300 |

Note: 1 m = 3.3 ft.
[a] L = length defined in Figure 9.

**Figure 8. Operational uniformity through consistent arrangement of successive exits.**

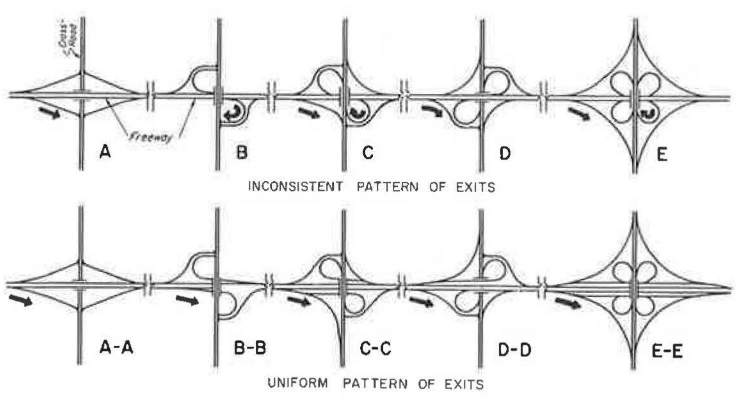
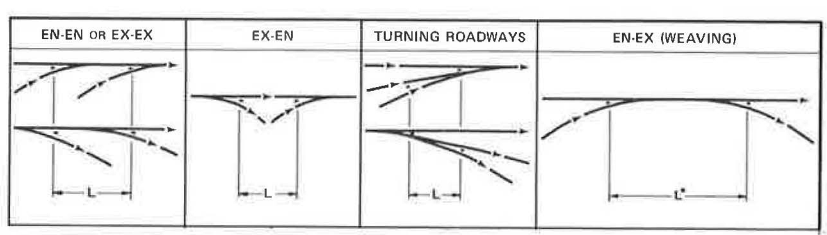



**Figure 9. Configurations for entrances and exits.**



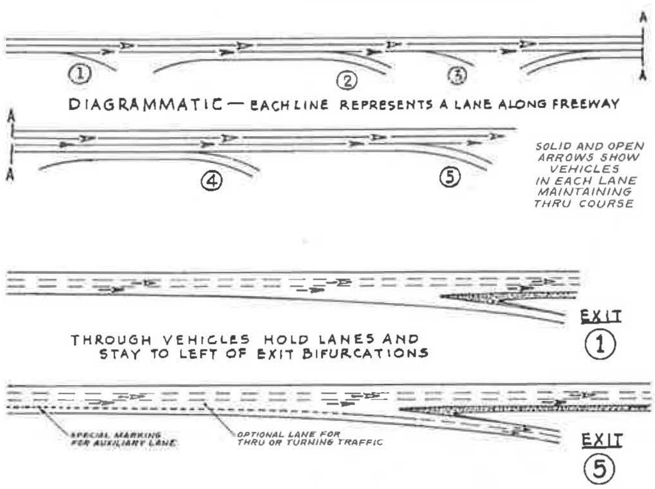
right-hand exit in advance of the crossroad, as illustrated in Figure 8. Such uniformity would require the construction of new freeways with this feature and the gradual replacement of outmoded interchanges by new ones that conform to the pattern. This would involve a long-range program, but its implementation would improve operations and safety. The anticipatory aspects provided by the visual and communicative features of a consistent exiting configuration would contribute significantly to the driver's confidence, assurance, and comfort.

Another feature of operational uniformity is that of the spacial relations, the sequencing and spacing of exits and entrances, along a route. The operation of the Interstate system throughout its development has demonstrated the need for greater spacing. Suggested values for new designs and for reconstruction of existing facilities that are built to the configurations illustrated in Figure 9 are given in Table 1.

Another communicative aspect in interchange design is the question of whether the crossroad passes over or under the major facility. The crossroad-over arrangement is much more favorable. The operational advantages of this configuration are more than simply the assistance of gravity for deceleration on up-ramps and acceleration on down-ramps. The advance view of the grade-separation structure and much of the exit ramp allows the driver exiting from the highway to fully appraise the situation and prepare for the necessary maneuver, and the driver on the entrance ramp has a good view of both the ramp and the freeway that enables him or her to pick a gap in traffic for merging, which provides visual assurance and the ability to perform more effectively.

For crossroads along highways in rural environments, particularly in sparsely settled areas where long trips at high, sustained speeds are common, the over arrangement also helps to lend interest and minimize driving monotony.

Figure 10. Operational characteristics with route continuity.




## Lane Balance

The arrangement of lanes on facilities having diverging, merging, and weaving traffic, referred to as lane balance, is significant in aiding the driver in all levels of the driving task—vehicle control, guidance, and navigation. Lane balance is mandatory for achieving smooth operation, reducing lane changing to a minimum, and clarifying the paths to be followed. It also involves the addition of auxiliary lanes and the loss by the associated lane drops (10).

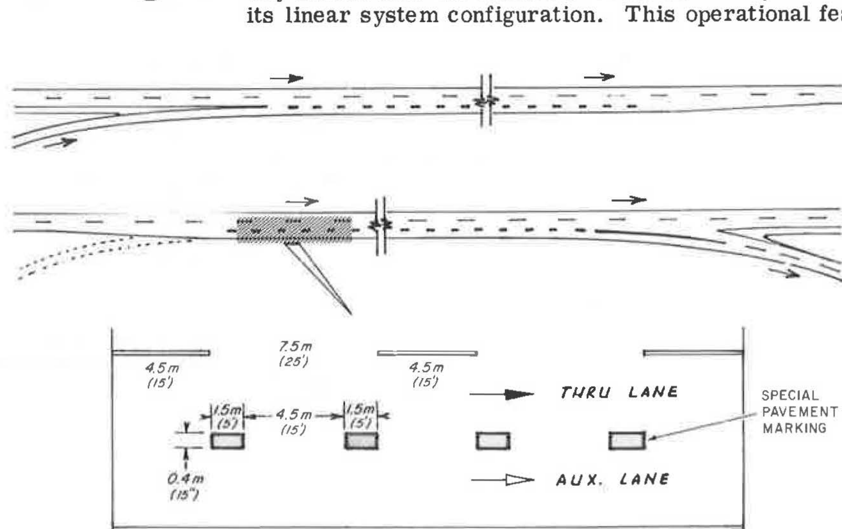
The lane relations at exits require one more lane going away than the combined number of lanes on the freeway preceding the exit. The arrangement of lanes at entrances should be such that the number of freeway lanes beyond the merge should be equal to the sum of the lanes preceding the merge or this sum minus one.

The use of auxiliary lanes to balance the traffic load and maintain a more uniform level of service on the highway is a relatively new technique. Such added lanes facilitate the positioning of drivers at exits and in bringing them onto the highway at entrances. Thus, the concept is very much related to route continuity and signing. An auxiliary lane has the potential for trapping a driver at its termination point or where it is continued onto a ramp or turning roadway. Consequently, the driver should be made aware when he is in or adjacent to an auxiliary lane, which should be marked in a special manner, as shown in Figures 10 and 11. The flexibility of operation with lane balance, especially as provided by the optional lane, is shown in the bottom illustration of Figure 10.

## Route Continuity and Designation

To keep the driver, particularly one who is unfamiliar with the highway, on his or her desired route, the freeway should have the feature of route continuity built into its linear system configuration. This operational feature

Figure 11. Suggested lane markings for auxiliary lanes.




Note: 1 m = 3.3 ft.

is the provision of a direct path along and throughout the length of a designated route—the designation pertaining to the route number or to the freeway name (9).

Route continuity is achieved by observing operational uniformity (all exits follow the same pattern), by maintaining lane balance, and by favoring the through-route characteristic (irrespective of volume splits at bifurcations) for the designated route. Its application is shown by comparative examples in Figure 12. This arrangement automatically provides complete lane continuity and allows the through driver to maintain a lane position throughout the entire route, which provides constant

Figure 12. Route continuity.

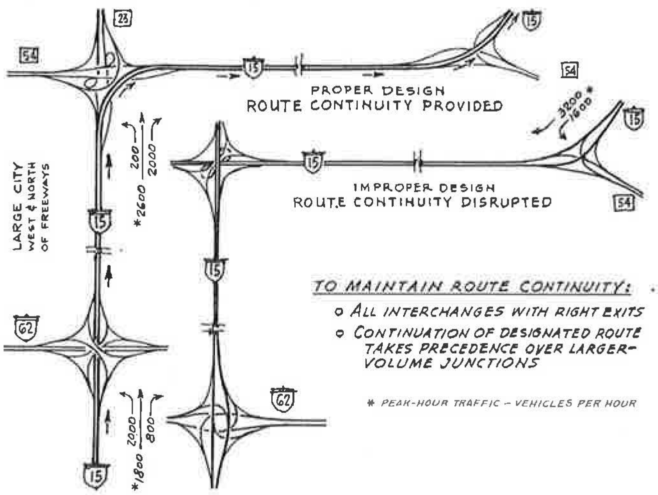



Figure 13. Route-designation configurations.

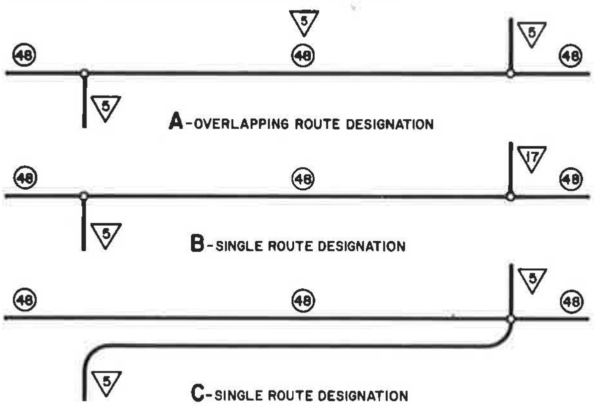



Figure 14. Signing for clarity and easy comprehension.

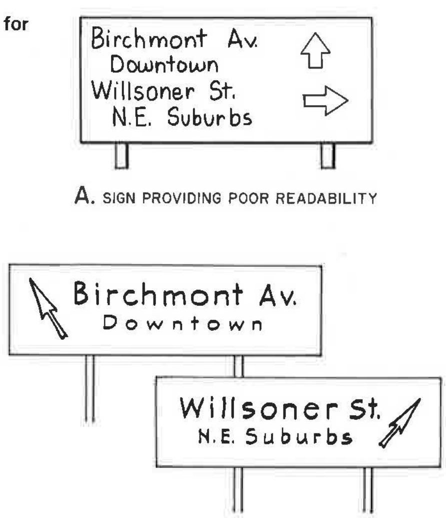



Figure 15. Directional sign posting on rural freeways.

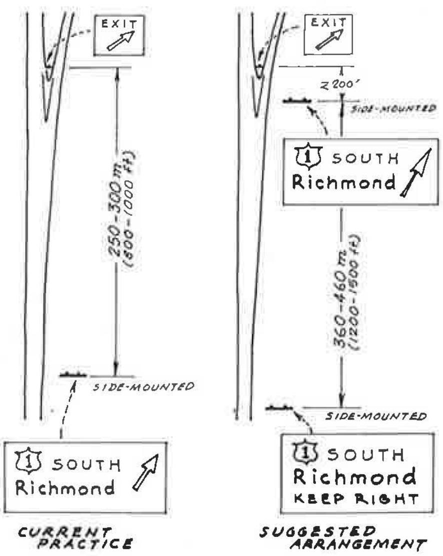



Figure 16. Directional signing for interchange with two-exit design (example).

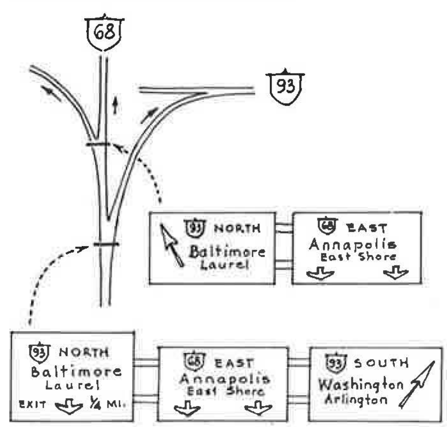



Figure 17. Directional signing for interchange with single-exit design (example).

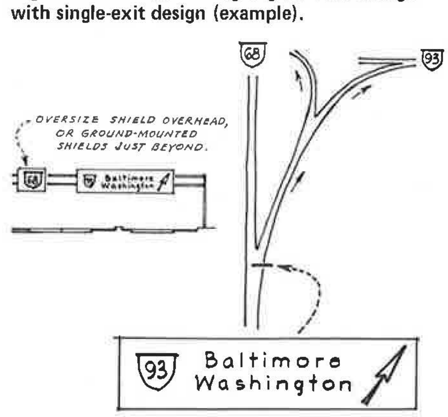
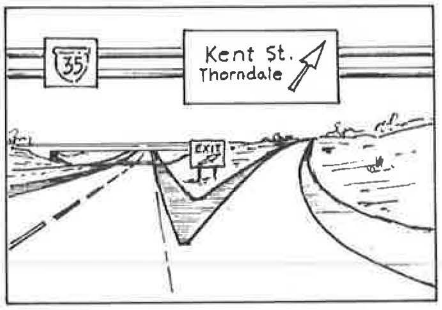


Figure 18. Coordination of geometry and signing at freeway exit.




visual assistance. As shown in Figure 10, the driver would need to diverge or change lanes only when choosing to exit from the designated route.

Route continuity significantly assists the driver in the driving task by eliminating lane changes for through drivers (except for passing) and by reducing lane changes and hazardous maneuvers for exiting traffic. The driver can operate with greater confidence, minimized anxiety, and the elimination of the elements of surprise and indecision.

A problem associated with route continuity is the need to redesignate and renumber various highway systems. Some numbers are now superfluous and should be dropped or reassigned. The overlapping of route numbers (roads that carry more than one number) on a given facility should be eliminated. This is illustrated in Figure 13. Although this will be a difficult task, the problem should eventually be resolved to clarify and simplify operations.

## Marking and Signing

To perform guidance and navigational tasks, the driver receives important information from control devices, such as marking and signing. Although there are highly effective control devices with a large measure of uniformity in current use (12), there are some features that need review and updating in the light of human-factors applications.

The lane markings of auxiliary lanes and the associated lane drops should be in conspicuous contrast to normal lane lines. The special marking suggested for this purpose (Figure 11) consists of a highly conspicuous lane separation made up of 2.5-m (5-ft) long by 40-cm (15-in) wide painted elements. The message conveyed by such markings would soon become obvious to the driver. The basic lanes, those continuing through on the facility, would always advise the through driver to stay to the left of the marking; the exiting driver would be told to position him or herself to the right of the marking; and the entering driver would be alerted to the necessity of crossing this marking to continue on the highway. This marking provides the driver with prior information and couples it with a visual indicator for positive guidance.

The design, composition, and placement of signs, although well standardized, need some upgrading for clarity and comprehension. There should be more effective separation, grouping, and accenting with variable letter sizes and weights of the various message units on a sign. An example of what could be done is shown in Figure 14. Another area that needs improvement is that of the number of sign panels at a given location and the separation of panel positions.

One weakness of standard directional sign posting in rural and suburban areas is the separation of the destination sign from the physical point of exit, as shown on the left of Figure 15. Here, the sign may be obscured from the driver in heavy traffic by trucks or by momentary inattention, which will create indecision, anxiety, or confusion for him or her. Or, at night the driver may be misled by the directional arrow and turn off onto the roadside in advance of the exit. The recommended arrangement is to provide an advance-warning sign that does not have an arrow and a second sign with an arrow in the vicinity of the gore to give the driver, through the combination of signs, positive guidance for the exit. This is shown on the right of Figure 15.

Figures 16 and 17 show the advantages of providing operational uniformity by the use of single-exit designs on the right (rather than two-exit designs and possibly left-hand ramps). The reduction from five signs on the freeway to only one improves the informational system and simplifies and reduces the driving task.

The information on freeway exit signs should be placed so that it integrates with other information that the driver will use to make the decision. This frames the routing information and the geometric and marking information within his or her visual field. For example, as shown in Figure 18, the placement and design of the exit ramp, its nose, and the signing and striping should all direct the driver toward the desired destination in a positive, reassuring, and consistent manner.

The amount of navigational information supplied to the driver is frequently too much to cope with at one time. Thus, there is a need to reduce and break down the information. This can be done by minimizing the number of message units per sign and by reducing the number of panels at any one location, as suggested in the guideline given below.

| Sign Panels at Location | Frequency of Use | Max Message Units per Sign | | Max Message Units per Assembly | |
|---|---|---|---|---|---|
| | | Desirable | Absolute | Desirable | Absolute |
| 1 | Frequently | 5 | 6 | 5 | 6 |
| 2 | Occasionally | 4 | 5 | 8 | 10 |
| 3 | Special case | 3 | 4 | 9 | 11 |
| 4 | Never | — | — | — | — |

## CONCLUSIONS

Although research in the field of human factors is continuing, there is already sufficient knowledge on the subject to permit its immediate application to the design and redesign of highway facilities and traffic-control devices.

Numerous geometric and control features and their response to human-factors inputs have been formulated and are discussed in this paper. Particular attention is directed to the features of design-speed application, alignment design and coordination, sight distance, cross-sectional delineation, operational uniformity and interchange design, lane balance, route continuity and designation, and marking and signing, and the way in which they are related to communicative aspects—the messages conveyed by the facility.

The guidelines suggested could be applied immediately and provide a starting point for improving design criteria on a larger scale and can significantly improve the operational efficiency and safety of both existing and new facilities.

## REFERENCES

1. G. J. Alexander and H. Lunenfeld. Positive Guid-

ance in Traffic Control. Federal Highway Administration, U.S. Department of Transportation, April 1975.
2. A Policy on Geometric Design of Rural Highways. AASHO, 1965.
3. Highway Design and Operational Practices Related to Highway Safety. AASHO, 1974.
4. Checklist of Driver Expectancy. AASHO, 1972.
5. T. W. Forbes, ed. Human Factors in Highway Traffic-Safety Research. Wiley, New York, 1972.
6. R. M. Michaels. Human Factors in Highway Safety. Traffic Quarterly, Vol. 15, 1961, pp. 586-599.
7. S. C. Tignor. Braking Performance of Motor Vehicles. Public Roads, Vol. 34, No. 4, Oct. 1966, pp. 69-83.
8. Dynamic Design for Safety. Federal Highway Administration, Seminar Notes, Oct. 1975.
9. J. E. Leisch. Highway Safety, Design, and Operations; Freeway Signing; and Related Geometrics. Special Subcommittee on the Federal-Aid Highway Program, House Committee on Public Works, U.S. Government Printing Office, May and July 1968, pp. 349-399 and 543-573.
10. J. E. Leisch. Lane-Determination Techniques for Freeway Facilities. Proc., Canadian Good Roads, 1965.
11. A Handbook of Highway-Safety Design and Operating Practices. Federal Highway Administration, U.S. Department of Transportation, 1973.
12. Manual on Uniform Traffic-Control Devices. Federal Highway Administration, U.S. Department of Transportation, 1971.

*Publication of this paper sponsored by Task Force for the Eighth Summer Meeting of the Transportation Research Board.*

# Characteristics of Trucks Operating on Grades

C. Michael Walton and Clyde E. Lee, Center for Highway Research, University of Texas at Austin

**The many changes in truck engine displacement and power have indicated a need to reassess current climbing-lane design practices. This study presents new data characterizing trucks (and combinations) on grades. Field data collected at several locations in central and east Texas were analyzed, and speed versus distance curves were developed for a range of grade profiles. From an evaluation of the speed versus distance curves for the designated critical-truck class, composite critical-length-of-grade charts were derived for an 88-km/h (55-mph) approach speed and a range of speed-reduction values.**

The criteria currently used for the design of climbing lanes for trucks have been developed over the last four decades and are based primarily on theoretical formulations and limited field observations.

This paper presents the findings of a study that obtained new field data about the operating characteristics of trucks on selected grades and related these data to geometric design standards for highway grades, with particular emphasis on the capacity and safety aspects of vehicle climbing lanes. The result of the project was the development of revised design charts relating the length and percent of a grade to the performance of a vehicle on that grade.

Most of the previous research on truck hill-climbing ability has been directed toward measurement of the elements that affect the performance of the vehicle. The roadway conditions, including rolling resistance, have been studied by Taragin (1) in his theoretical equation, and traffic conditions have been studied by Schwender, Normann, and Granum (2). The current American Association of State Highway and Transportation Officials (AASHTO) policy for the design of truck climbing lanes is based principally on data collected in 1954, and most states currently use a modification that accounts for special state and regional characteristics (13).

The performance of a vehicle operating on a highway is a function of the numerous variables associated with the principal elements that govern vehicular motion. These elements are the vehicle itself, the roadway and the environment in which the vehicle operates, and the behavior of the vehicle operator. The identification and evaluation of these elements provided an additional framework for the field study. Each element was described and arrayed for analysis in the mathematical modeling phase of the study.

## GENERAL EVALUATION OF VEHICLE GRADEABILITY

Because of the limited scope of the conventional force and energy equations, the mathematical models used in previous research have not been entirely successful in evaluating the effects of these variables in relation to actual vehicle performance. However, the models might be improved if new experimental data that represent the actual vehicle operating characteristics under a wide variety of roadway and environmental conditions were available (3). With this information, the performance characteristics of representative vehicles could be modeled, and the present design cr.teria for grades could be evaluated.

Collection of the field data necessary to adequately identify the operating characteristics of heavy vehicles on grades is a complex operation because of the numerous combinations of variables involved. However, a majority of the variables can be represented by field data from three major areas: (a) the pertinent physical characteristics of the vehicles under observation, (b) the speed versus distance profiles of the vehicles at selected field sites, and (c) the geometric and environmental external conditions under which the vehicles operate.