Abridgment

Decision Sight Distance for Highway Design and Traffic Control Requirements

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A primary feature in the design of a highway is the arrangement of the geometric elements so that there is adequate sight distance for safe and efficient vehicle operation. With this principle in mind, the American Association of State Highway and Transportation Officials (AASHTO) has established guidelines for three important types of sight distance: (a) stopping, (b) passing, and (c) intersection. These established distances, however, are often inadequate for situations in which drivers must make very complex decisions, the development of a potentially hazardous situation is difficult to perceive, or severe braking is inappropriate. For locations where longer sight distances are needed, a review of human factors and aspects of traffic operations shows that sight-distance criteria should be based on the driver's ability to properly react to impending danger. This concept has been referred to as decision sight distance.

Decision sight distance (DSD) has been defined as the distance at which drivers can detect a hazard or a signal in a cluttered roadway environment, recognize it or its potential threat, select an appropriate speed and path, and perform the required action safely and efficiently (1). Research was performed to relate this concept to specific road types, design speeds, traffic operating conditions, geometric features, and driver attributes. The work was done in two phases:

1. In phase 1, a model of the hazard-avoidance process was formulated to be used as a basis for quantifying DSD, and preliminary DSD values were developed based on the average times for the elements of the model derived from literature sources.
2. In phase 2, 19 subjects drove an instrumented vehicle through eight typical highway situations to validate the preliminary DSD values.

HAZARD-AVOIDANCE MODEL

An analytic assessment of the definition of DSD and its components led to the formulation of a model for quantifying appropriate distances. The model outlines a sequential chain of events that occurs in hazard avoidance, starting from detection of the hazard and ending with completion of the avoidance maneuver. This process is adopted and modified from one originally developed by Baker and Stebbins (2), which was in turn later modified by Leisch (3) and Pfefer (4). The steps in the process are briefly described as follows:

1. Sighting (time t_0)—This is the baseline time point at which the hazard is within the driver's sight line.
2. Detection (time t_1)—The driver's eye fixates on the hazard and "sees" it.
3. Recognition (time t_2)—The image on the eye is translated by the brain, and the hazard is recognized or perceived as such.
4. Decision (time t_3)—The driver analyzes alternative courses of action and selects one.
5. Response (time t_4)—The driver initiates the required action.
6. Completion of maneuver (time t_5)—The driver accomplishes a change in the path and/or the speed of the vehicle.

The process as described above is a simple additive model in which the total time from the moment when the hazard is visible to the completion of the hazard-avoidance maneuver equals the sum of the incremental times required for detection (t_0 to t_1), recognition (t_1 to t_2), decision (t_2 to t_3), response (t_3 to t_4), and completion of maneuver (t_4 to t_5).

PRELIMINARY DSD VALUES

Data for quantifying the various components of the model were taken from the existing literature. For a complete discussion of the findings from previous research on the various components of the hazard-avoidance process, the reader is referred to McGee and others (5).

From the literature on DSD parameters, it was clear that there are gaps that make it difficult to quantify distance values for various conditions. Many variables can affect each of the components in the detection-through-maneuver process. These variables can be grouped in the following categories: driver capabilities, design features, and traffic operation factors. Unfortunately, the state of the art is not sufficiently advanced to quantitatively describe how these and other factors may affect each component of the model.

At best, a range of values could be developed by using the literature findings as a basis. Such an approach has been followed in preparing the following table, which gives the preliminary time values for the various elements of the hazard-avoidance model:

Phase	Time (s) Low	Time (s) High
Before maneuver		
Detection and recognition	1.5	2.0
Decision and response	4.2	7.1
Maneuver (lane change)	3.5	4.5
Total	9.2	13.6

As this table indicates, the ranges of values were grouped into two phases:

1. The before-maneuver phase, which consists of (a) detection and recognition and (b) decision and response initiation, and
2. The maneuver phase, in which lane changing was used as the maneuver.

VALIDATION OF DSD VALUES

Since the existing literature was only marginally ade-

Table 1. Recommended DSD values.

Design Speed (km/h)	Time (s): Before Maneuver: Detection and Recognition	Decision and Initiation of Response	Maneuver (lane change)	Total	Decision Sight Distance (m): Computed	Rounded for Design[a]
40	1.5-3.0	4.2-6.5	4.5	10.2-14	113-156	120-160
60	1.5-3.0	4.2-6.5	4.5	10.2-14	170-233	170-230
80	1.5-3.0	4.2-6.5	4.5	10.2-14	227-311	230-310
100	2.0-3.0	4.7-7.0	4.3	11.2-14.5	306-397	310-400
120	2.0-3.0	4.7-7.0	4.0	10.7-14	357-467	360-470
140	2.0-3.0	4.7-7.0	4.0	10.7-14	416-544	420-540

Note: 1 km = 0.62 mile; 1 m = 3.28 ft.
[a]Rounded up to the nearest 10 m for the low value and up or down to the nearest 10 m for the upper value.

quate for quantifying certain portions of the hazard-avoidance process and ultimately for estimating DSD values, field work was performed to operationally validate the preliminary DSD values.

The methodology for conducting this field validation was designed to develop time estimates for the following combinations:

1. Detection and recognition—time elements t_0 to t_2,
2. Decision and initiation of response—time elements t_2 to t_4, and
3. Avoidance maneuver—time elements t_4 to t_5.

Nineteen test subjects drove over a course and responded to certain geometrics (primarily lane drops) that necessitated a change in path and possibly in speed in order to reach the destination objective. The responses sought included the initial sighting of the geometric feature (detection plus recognition), the moment of initiation of a change in path and/or speed (decision plus initiation of response), and finally the time used to complete the maneuver (avoidance maneuver).

Validation of the preliminary DSD criteria developed from the literature would be attained if one or both of the following results were found:

1. The times recommended for the various components of the hazard-avoidance process were replicated by several subject drivers, and
2. At sites where the existing sight distance was shorter than the recommended decision sight distance, drivers could not negotiate the situation safely and efficiently, and, conversely, at sites where the sight distance was equal to or greater than the recommended decision sight distance, drivers had no problem negotiating the required change in path and speed.

The first validation criterion was only partially met. For the detection-plus-recognition phase, times greater than the maximum value of 2.0 s were observed in many cases. However, the high values were not considered to be indicative of the actual time required for this phase of the hazard-avoidance process. In view of the results, a range of 1.5-3.0 s seemed more appropriate. The lower value suggested in the table above appears to be the minimum required, whereas 3.0 s would be required in more complex situations.

The results of the field data for the decision-plus-response time were reasonably compatible with the analytically developed criteria. Although higher times were observed, it is believed that, depending on vehicle speed, the upper range of 6.6-7.1 s is a good design criterion for the more complex situations and that 4.2-4.7 s is adequate for the less demanding situations.

The most nearly replicated time value was the maneuver time. The preliminary DSD criterion allows times of 4.5 s for 48.3 km/h (30 miles/h) to 3.5 s for 112.7-128.7 km/h (70-80 miles/h). Based on the results of the field experiment as well as a reanalysis of data from a previous study, it appears that a value of 4.5 s is appropriate for speeds at least as high as 96.6 km/h (60 miles/h). Design values for higher speeds should probably be 4.0 rather than 3.5 s.

The second of the two validation criteria given above was met. At four sites where the maximum sight distance was greater than the DSD, the subjects successfully negotiated the course; that is, they were able to recognize the potential hazard situation and responded to it safely and efficiently. At the other four sites that had inadequate sight distance, several subjects could not negotiate the sites properly.

RESULTS AND RECOMMENDED VALUES

In view of the findings of the literature synthesis and the results of field validation experiments, it is concluded that the concept of decision sight distance is operationally valid. Drivers do need a sight distance of the roadway that gives them ample time to detect and recognize a potential hazard, decide on the proper course of action, and complete the required maneuver in a safe and efficient manner. This sight distance depends on the driver's ability to process information and to maneuver the vehicle, and these factors in turn are related to the level of decision complexity, the visual clutter, and the surrounding traffic.

From analytic and limited empirical research, it is possible to recommend a range of DSD values. These values, which are given in Table 1, have been divided into before-maneuver and maneuver phases. The before-maneuver phase is the time required for a driver to process information relative to a hazard. It consists of the time needed to (a) detect and recognize the hazard and (b) decide on the proper maneuver and initiate the action. The second phase is the maneuver time. Since a lane change is likely and more time is consumed in changing lanes than in reducing speed, a lane-change maneuver is assumed in Table 1.

The last column in the table gives the recommended DSDs. In the range of values provided, the lower value is the minimum acceptable for situations of moderate complexity or visual clutter and the upper value is desirable for highly complex or visually cluttered situations. Unfortunately, because of the limitations of this study, it is not possible to provide specific criteria for the level of decision complexity or clutter.

For design purposes, DSDs should be from the driver's eye height to an object of zero height, since the driver must be able to see the entire roadway. A higher limit can be used if some other physical feature provides the hazard information to the driver.

RECOMMENDED APPLICATIONS

Two applications of DSD are recommended. First, it should be used in highway design, either for new facilities or reconstruction (improvement) of "below-standard" facilities. The locations where DSD should be applied are generally characterized by conditions that create the potential need for drivers to depart from simple steering and speed-control maneuvers to follow the road. DSD is also recommended for use at special-feature locations where drivers could experience problems in handling information. These locations generally include interchanges—especially freeway-to-freeway—intersections, toll plazas, pavement-width reductions (lane drops), and any other location where unusual or unexpected maneuvers are required.

For all design situations, the higher values are suggested for especially complex areas such as interchanges that have left-hand exits or multiple exits in close proximity. The lower values should be considered minimally acceptable.

The second suggested application is for traffic control techniques at hazardous locations. More specifically, the criteria can be used to determine the need for and location of advance warning signs. In using Table 1 to determine the appropriate DSD, the 85th percentile speed rather than design speed should be used. In addition, although the higher values are recommended for defining the DSD, ranges of values are given to provide the flexibility that is often required in the positioning of advance warning signs.

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Use of Overland Flow in Storm-Water Management on Interstate Highways

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An assessment of the potential of shallow-water ditches and shoulder areas adjacent to roadways for deposition of heavy metals is reported. The metals examined in the field were those that result from automobile emissions and the wear of automotive parts: lead, zinc, copper, chromium, and nickel. Cadmium content was also measured. The highest concentrations of metals were found in roadside plant and animal populations. These, however, contained the least metals in mass. Soils adjacent to the edge of the pavement contained the greatest mass of metals. In general, the topsoil contained higher concentrations of metals than subsurface soils. Lead was shown to be relatively immobilized by the soil, whereas other metals were more mobile. Design equations for estimating the volume of shallow-water storage areas for rainfall excess (runoff) are presented. In general, the use of overland flow with shallow ditch areas was shown to be effective for the control of runoff and its associated pollution content.

Storm-water runoff in the United States is receiving considerable attention, primarily as a result of federal regulations such as the Federal Water Pollution Control Act and the Clean Water Act. Runoff pollutants from highway surfaces had been documented as early as 1957 (1), when high concentrations of lead in soils adjacent to highways were reported. More recent studies (2, 3) have identified zinc, copper, chromium, cadmium, nickel, and other metals in highway runoff waters. On a mass basis, Shaheen (2) compared highway runoff with sanitary sewage for comparable land uses and populations and determined that the masses of lead, zinc, and chromium in highway runoff were, respectively, 1000, 20, and 300 times greater than amounts of those metals encountered in sanitary sewage. Such a comparison should be viewed with caution, however, because the chemistry of highway drainage and its mode of discharge are very different from those of sewage effluent.

The automobile is the predominant source of lead, as well as some other heavy metals, near highways. The combustion of leaded gasoline is generally acknowledged to be the major source of lead, but some lead also results from the wear of tires, in which lead oxide is used as a filler material (2). Zinc also results from tire wear and from the leakage of crankcase oil, in which high concentrations of zinc are used as a stabilizer (1). Chromium, copper, and nickel are produced by the wear of metal plating, bearings, bush-