Abridgment

Evaluating Location Effectiveness of Freeway Directional and Diversion Signs

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The location of freeway directional signs or signs displaying real-time messages informing drivers of downstream exit or diversion points is important to providing safe and efficient traffic operation at these points.

The costs and the operating and maintenance problems of real-time information signs usually allow only a single sign before a diversion point. Although the visibility of this kind of sign is hardly a problem, its location is critical and should be determined analytically.

For directional exit signs, the spacing and number specified by current practice generally provide adequate maneuvering distance. However, in certain situations a different sign arrangement should be quantified to determine its better potential effectiveness. This can be done by calculating the theoretical probability of completing a lane change, under various traffic flow conditions, within a certain distance determined by the size and location of a sign.

The following model uses gap acceptance concepts and considerations for safe manuvering to calculate the above probability and to evaluate the effectiveness of various sign locations.

MODEL DESCRIPTION

The Lane-Change Process

A vehicle is traveling on lane $i + 1$ at time mean speed U_{i+1} next to a traffic substream on lane i that is also traveling at U_{i+1} (in this case $U_{i+1} > U_i$). The probability density function of headways on the ith lane may be denoted by $\theta_i(t)$, where t is a certain time needed for a lane change (to the right adjacent lane) established by the driver. Here the lane-change process begins.

The driver changing looks at adjacent lane i and considers some or all of the following:

1. The speed of the approaching (lagging) vehicle on lane i,
2. The relative position of the lead vehicle on lane i,
3. His or her own speed and operational characteristics, and
4. His or her own gap acceptance characteristics.

At time $t + T$, where T is the driver's decision time, the driver either accepts the gap and changes lanes or rejects it. Rejection means that the driver's critical gap (the point at which anything shorter is unacceptable) has been exceeded. When the gap is accepted, the lane-change maneuver begins the moment a safe maneuver can be accomplished. If the gap is rejected, the driver increases speed, begins evaluating the next gap, and reaches a decision concerning that gap.

The lane-change process may be full or partial. The full process occurs in either of the following situations: (a) the gap encountered immediately after the need for a lane change has been established is rejected because it is smaller than the driver's critical gap; (b) the gap is larger than the critical gap, but the driver's position relative to the lead vehicle in it makes a lane change seem hazardous, and the gap is rejected.

The full process consists of the following three phases: phase 1 is waiting for an acceptable gap or lag; phase 2 is bringing the vehicle to such a position relative to the accepted gap that the maneuver can begin; and phase 3 is the actual lane-change maneuver.

A partial process will occur if the first encountered gap is accepted. This takes place in one of the following two forms. The driver needs to adjust position relative to the accepted gap before a safe maneuver can be initiated, or the dirver's relative position allows immediate initiation of the lane-change maneuver. Each of the forms consists of phases 2 and 3.

Each phase in the various forms of the lane-change process has its own distribution function with respect to distance. These functions are themselves functions of the actual traffic conditions. The expression $f_i(x_i, \bar{V}, \bar{U})$ denotes the distribution functions of the distance x required to complete phase 1 under volume condition $\bar{V}$ and speed condition $\bar{U}$ for a particular type or form of the process. $\bar{V}$ and $\bar{U}$ are vectors that represent traffic flow rate and time mean speed, respectively, on the lanes of a one-way freeway section during the time of the process.

Any function representing any phase of the process is considered independent of those characterizing other phases for a given set of speed and volume conditions. The distribution functions (f) of the distance required to complete the various lane-change processes were considered as the convolutions of the individual distribution functions (F, A, and B) describing each phase (1, 2, and 3) in the appropriate form of the process and can be presented as follows.

The full process is

$$f_F(x,\bar{V},\bar{U}) = f_{1F}(x_1,\bar{V},\bar{U}) \times f_{2F}(x_2,\bar{V},\bar{U}) \times f_3(x_3,\bar{V},\bar{U}) \quad (1)$$

The partial process, form A, is

$$f_A(x,\bar{V},\bar{U}) = f_{2A}(x_2,\bar{V},\bar{U}) \times f_3(x_3,\bar{V},\bar{U}) \quad (2)$$

and the partial process, form B, is

$$f_B(x,\bar{V},\bar{U}) = f_{2B}(x_2,\bar{V},\bar{U}) \times f_3(x_3,\bar{V},\bar{U}) \quad (3)$$

The composite distribution representing the combination of the various lane-change processes from one lane to the adjacent lane for a given set of volume and speed conditions is as follows:

$$f(x,\bar{V},\bar{U}) = a_F f_F(x,\bar{V},\bar{U}) + a_A f_A(x,\bar{V},\bar{U}) + a_B f_B(x,\bar{V},\bar{U}) \quad (4)$$

where a_F, a_A, and a_B are the probabilities of occurrence of the three types of the process. A full development of the model is given elsewhere (1). A more complicated expression could be developed for lane change in a three-lane section.

Figure 1. Lane-change distance-cumulative probability relationship for four-lane, two-way freeway.

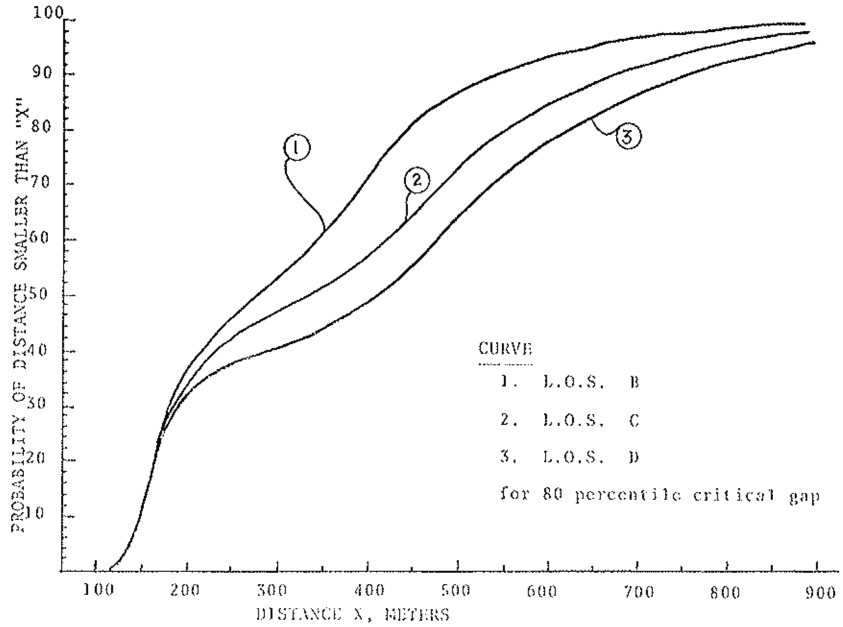

Table 1. Distance in advance of signs at which lane-change decisions are made.

Level of Service	Speed on Origin Lane (km/h)	Distance (m)		
		Real-Time Sign	Exit Area Sign	1.6 and 3.2-km Signs[a]
B	91	340	180	106
C	82	345	189	111
D	75	349	192	115

Note: 1 m = 3.3 ft; 1 km = 0.62 mile; 1 km/h = 0.62 mph.
[a] 1 and 2-mile signs.

Table 2. Effectiveness of location of directional and diversion signs.

Sign Type	Distance (km)	Level of Service[a]		
		B	C	D
Directional	From exit	0.26	0.25	0.25
	1.6 before	0.80	0.80	0.80
	3.2 before	0.80	0.80	0.80
Diversion	From diversion point	0.48	0.40	0.35
	0.4 before	0.78	0.75	0.70
	0.8 before	0.80	0.80	0.80

Note: 1 km = 0.62 mile.
[a] Based on the 80th percentile critical gap.

Data Collection and Analysis

A three-lane section of the Gulf Freeway in Houston, Texas, was selected for this study. Data on traffic stream speeds and lane flow rates were collected by the Freeway Control Center during a dry 2-week period. An instrumented vehicle driven by a test driver was used to obtain data on the following: delay in making a lane change to the next lane once an instruction for a change was given and the distance traversed during the lane-change process.

Nearly 500 lane changes were performed, of which approximately 450 occurred at freeway levels of service B, C, and D. The critical gap characteristics of the test driver were determined by field measurements of the angular velocity, and the characteristics of the headway distribution function $\theta_i(t)$ on the freeway lanes were assumed to be of an Erlang nature. The value of the parameters varied according to flow rates given by Drew, Buhr, and Whitson (2).

How well the collected data fit the developed model was determined by using the Kolmogorov-Smirnov test (3) and was found to lie at the 1 percent level of significance.

DEVELOPMENT OF LANE-CHANGE DISTANCE-PROBABILITY RELATIONSHIP

As discussed above, the characteristics of the lane-change distance-probability relationship are partly a function of traffic flow rates and speeds on the origin and destination lanes and driver's gap acceptance characteristics.

The relationship between traffic speeds and flow rates on a four-lane freeway was investigated by Webb and Moskovitz (4). Lane values for speed and flow rate for levels of service B, C, and D were derived from this relationship. And the relationship between the driver's critical gap and his or her threshold angular velocity in the gap acceptance process, developed by Michaels and Weingarten (5), is shown in the following equation:

$$T = [(w/\psi U_i^2)(U_{i+1} - U_i)]^{1/2} \qquad (5)$$

where W is car width and ψ is the driver's threshold angular velocity. It was Rock (6), in his studies of driver's threshold angular velocity, who established the cumulative distribution of this parameter.

The inverse relationship between threshold angular velocity and critical gap suggests that the P percentile angular velocity corresponds to the (i - P) percentile critical gap. The lane-change distance-probability curves were developed for the 80th percentile critical gap of 27×10^4 radians/s, meaning that 80 percent of drivers changing lanes are expected to complete their maneuvers within a certain distance with a certain probability determined by the appropriate curve.

Figure 1 shows the developed lane-change distance-cumulative probability curves for a four-lane freeway for levels of service B, C, and D for the 80th percentile critical gap.

EFFECTIVENESS OF LOCATION OF DIVERSION AND DIRECTIONAL SIGNS

A sign's legibility distance will determine when a driver will decide to change lanes. According to current practice, the desired legibility distance of such signs is 19.5 m (65 ft) per 2.5 cm (1 in) of letter height for daylight conditions, assuming that drivers have 20/20 vision.

For real-time information signs with 50-cm (20-in) letter height and a perception-reaction time of 2 s, a need for a lane change could arise 390 - (1.4 × U m) [1300 - (2.94 × U ft)], where U is the driver's speed in kilometers per hour in advance of the sign.

The Manual on Uniform Traffic Control Devices says that the letter height for the exit area sign is 30 cm (12 in) and is 20 cm (8 in) for both the 1.6-km (1-mile) and 3.2-km (2-mile) signs. With such a sign arrangement and a perception-reaction time of 2 s, a need for a lane change could arise 234 - (1.4 × U m) [780 - (2.94 × U ft)] in advance of the exit sign and 156 - (1.4 × U m) [520 - (2.94 × U ft)] in advance of each one of the other two signs.

Data from the volume-speed relationships developed by Webb and Moskovitz (4) give the speeds on the origin lane shown in Table 1. For real-time information and directional signs these speeds correspond to the distances in advance of the sign in the table.

The probability or effectiveness values for the specified locations of the directional and real-time information signs with respect to diversion points were derived from Figure 1. These values apply to only 80 percent of the driver population, but they were adjusted to represent the effectiveness of the location of signs for the total driver population. The adjusted values are presented in Table 2.

The above analysis considers each sign as if it were the only one there and ignores the effects of similar upstream signs. From Table 2 it can be seen that there is not much difference in the effectiveness of the directional sign at the exit area for the various levels of service, and both the 1.6-km and 3.2-km directional signs are equally effective.

As to the real-time information sign of 50-cm letter size, the variations in the effectiveness of a sign located at the diversion point are quite considerable for the three levels of service, as illustrated in the curves in Figure 1.

The effectiveness values shown in Table 2 indicate the percentages of drivers who will accomplish the lane-change maneuver with reasonable safety and comfort.

CONCLUSIONS

It seems that the probability curves for the distance involved in a lane-change maneuver on a four-lane freeway provide a reasonable measure of effectiveness of a location of a sign. This measure relates to the probability of accomplishing the maneuver under reasonably safe and comfortable conditions.

An evaluation of the current practice of locating directional signs reveals that both the 1.6-km and 3.2-km signs are approximately the same in effectiveness. Except for improving the visibility of the message, the contribution of the 3.2-km sign to the success of the lane-change maneuver can be considered rather small. Improving these signs or changing their locations with respect to exit points could reduce the number of signs needed.

As to real-time diversion signs of 50-cm letter height on a four-lane freeway, the gain in effectiveness from locating a sign more than 0.4 km (0.25 mile) in advance of the diversion point is relatively small.

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The contents of this paper reflect my own views, not those of the Illinois Department of Transportation, and I alone am responsible for the facts and accuracy of the material presented.

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