Analysis of Side-Mounted Turn Signal Safety Benefits

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A 1973 National Highway Traffic Safety Administration (NHTSA) Notice of Proposed Rulemaking would require that all passenger cars, multipurpose vehicles, trucks, and buses be equipped with side-mounted turn signals. It is evident from the side turn signal lamp photometrics specified in the notice that the signal is intended primarily to alert a driver overtaking in an adjacent lane that the vehicle displaying the signal is preparing to change lanes in his or her direction. The side turn signal would supplement the rear turn signal by providing a clear display to an overtaking driver who is too far forward with respect to the lead vehicle to be able to see its rear turn signals. Consideration of other driving situations revealed no commonly occurring set of vehicle relationships in traffic in which a side turn signal would provide a crucial message. However, because rear turn signals are visible through most of an overtaking maneuver and because, in any case, many drivers do not use turn signals when changing lanes, the safety benefit of side turn signals even in overtaking situations is not obvious. In accordance with this, an analysis was undertaken to obtain an estimate of the accident and dollar savings that might be realized from the installation of side-mounted turn signals on passenger cars.

An analytical model was developed that predicts the probability of an accident with and without a side turn signal given that the lead driver makes a blind lane change; that is, the decision to change lanes is independent of the presence or absence of an overtaking vehicle. Annual side turn signal benefits were then estimated by calculating the number of vehicles saved from being in accidents through provision of a side turn signal.

The analytical procedure involved three different tasks. First, an adjacent lane overtaking model was developed that defined the overtaking situations in which an accident would occur under each of several different environmental conditions. Next, a probability model was employed to estimate the accident likelihoods under each of these conditions. Finally, a survey of accident data yielded the relative accident frequencies of these conditions and also produced an estimate of the overall number of lane-change crashes expected to occur each year.

OVERTAKING MODEL

The essential features of the model and many of the assumptions are shown in Figure 1, which delineates the areas in closing rate and following distance space in which an accident can or cannot be avoided by braking should a driver make a blind lane change into the lane occupied by an overtaking vehicle. The ordinate is following distance measured from the front of the overtaking vehicle to the front of the lane-changing vehicle. Both vehicles are assumed to be 5.4 m (18 ft) long. The abscissa is closing rate, the speed of the overtaking car minus the speed of the lead car.

Braking

The normal reaction time curve a1 is a boundary condition representing the minimum following distance for each closing rate at which the overtaking car can avoid an accident by braking. This curve is a plot of the equation

$$D = (\Delta v^2/9.81\ g) + RT\Delta v \qquad (1)$$

where

- D = following distance as previously defined in meters,
- g = deceleration in g's as a fraction of the gravitational constant,
- RT = overtaking car driver reaction time in seconds, and
- Δv = closing rate in kilometers per hour.

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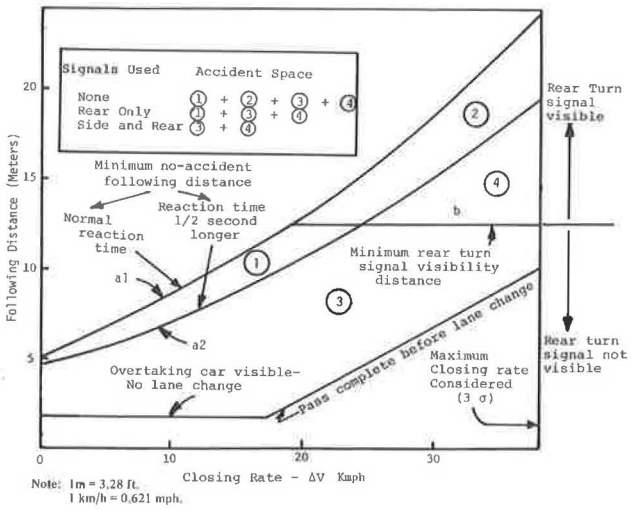
Figure 1. Combinations that will cause lane change accidents.



Reaction Time and Effect of Turn Signals

The central premise in the analysis is that the effect of turn signals is to reduce driver reaction time to the start of a lane change by 0.5 s. This figure derives from the assumptions that the initial lateral displacement on the part of a lead car will not be interpreted by the following driver as the start of a lane change unless the lead car is displaying a turn signal. Curve a2 in Figure 1 is a plot of equation 1 with a 0.5-s shorter reaction time.

A reaction time distribution rather than a single value was used in the analysis. That is, accident probability computations were made for various reaction times and weighted by the relative probabilities of the reaction times. The distribution is $\log_{10}$ normal with a mean of 1.42 s and a standard deviation (σ) of the $\log_{10}$ reaction times of 0.4458. Four-tenths of a second is added to the distribution to represent foot movement time. For the purposes of the analysis, an additional 0.5 s of recognition time was added to the distribution to represent signal-absent reaction times, according to the previous discussion. The application of the distribution to the probability model is described further in a later section.

Rear Turn Signal Range

Line b in Figure 1 is a graph of D = K where K = the minimum distance at which an overtaking driver can see the rear turn signals of the car in the adjacent lane. This distance depends on whether it is day or night and whether the overtaking vehicle is passing on the right or left side.

Accident Space

The accident space in Figure 1 is divided into four areas by line b and curve a2. Accidents above line b (areas 2 and 4) are those in which the lane change starts with the overtaking vehicle within the visible rear turn signal range of the lead car. In other words, these are accidents that will not be affected by the presence or absence of a side turn signal because the rear signal is visible. At lesser following distances, rear turn signals are assumed not to be visible, and this is the area in which a side turn signal might be of benefit. The effect of a turn signal, side or rear, is to reduce the total accident space; that is, the upper boundary becomes a2 rather than a1. Therefore, the area between a1 and a2 (area 1 plus area 2) represents the accident savings attributable to a turn signal. In particular, area 1 represents the savings in accidents attributable to a side turn signal; area 2 represents the savings attributable to a rear turn signal. If all current drivers used turn signals (rear only), then the total accident space can be represented by the sum of areas 1, 3, and 4. If no drivers use turn signals, then the total accident space is represented by the sum of all four areas.

Obviously, the outcome is dependent on the frequency of turn signal use. In a brief study conducted by the Ford Motor Company to establish turn signal use frequency, turn signals were found to be used at or prior to lane changing 42 percent of the time on freeways and 38 percent of the time on multilane streets and highways.

ACCIDENT PROBABILITY

The probability of an accident in a region N (where N is 1, 2, 3, or 4) of Figure 1 given a blind lane change is

$$P(N) = P(d)_{\Delta v,RT} \int_{\Delta v=0}^{\Delta v\ max} \int_{RT\ min}^{RT\ max} P(RT)\, P(\Delta v)\, d\Delta v\, dRT \qquad (2)$$

where

$d_{\Delta v,RT}$ = minimum no-accident following distance and

$P(d)_{\Delta v,RT}$ = probability that there is an overtaking vehicle in the adjacent lane with a following distance equal to or less than $d_{\Delta v,RT}$ at the start of the lane change.

The range of RT is $\pm 3\sigma$ and the upper bound on v is at 3σ. $P(d)_{\Delta v,RT}$ was computed by using an exponential expression for the distribution of headways. Numerical methods were used to approximate the integrals in steps of $\sigma/10$.

By changing boundary conditions to reflect the presence or absence of a side turn signal and the use or nonuse of turn signals, one can approximate the probabilities associated with the four regions in Figure 1. These are then inserted into the following equation to determine the proportion of accidents saved by the provision of a side turn signal:

$$P(S) = \frac{QP(1)}{(1 - Q)\,[P(1) + P(2) + P(3) + P(4)] + Q[P(1) + P(3) + P(4)]} \qquad (3)$$

where Q = proportion of drivers using turn signals.

ACCIDENT DATA AND COSTS

About 0.77 million passenger cars are involved each year in same-direction crashes between vehicles. Based on National Safety Council and NHTSA data, the average cost per vehicle in a same-direction crash was estimated to be $690. An analysis of accident data files was performed to develop the distribution of these accidents across those environmental conditions that determine the values of some of the overtaking model parameters (K depends on whether it is day or night, braking deceleration depends on weather, and turn signal usage depends on the type of highway). To obtain an estimate of total percentage of accident savings, equation 3 was computed for each condition and the resulting values of P(s) were summed with appropriate weights.

ACCIDENT AND DOLLAR SAVINGS

The following tabulation gives the expected yearly bene-

fits attributable to the introduction of a side turn signal system after complete installation of the device in the roadway system. The average benefits for the first 10 years of installation are presented, which may be a more representative assessment of the true benefit when one considers the long implementation lag times (the full life savings potential of any device is not reached in the early years because not all vehicles on the road are equipped):

Item	Accident Savings (vehicles)	Cost Savings ($)
Average annual savings after 100 percent introduction	9625	6 640 000
Average annual savings over 10-year introductory period	5066	3 500 000

According to the National Safety Council, 25.1 million vehicles were involved in accidents in 1974. As indicated in the previous tabulation, the introduction of side turn signals could reduce this figure by an average of about 5066/year over the 10-year introductory period. This reduction represents about 0.02 percent of the 1974 total of 25.1 million.

COSTS AND BENEFIT-COST RATIO

In 1973, the average cost of a side turn signal to the consumer was estimated to be $7.55. At the 1974 rate of sales (8.9 million passenger cars), the average annual cost of implementing side turn signals would be $67 million. The rate of the 10-year average annual benefits to average costs is $3.5 million/$67 million = 0.052. Estimates of benefit-cost ratios for certain Federal Highway Administration programs and high payoff vehicle safety standards range from 4 to 80. The side turn signal thus not only is an inefficient measure when considered on its own merits but also compares poorly with other highway and vehicle safety programs.

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A complete version of this paper is available from the authors.