APPENDIX 5: DRIVING MEASURES

Using ideas derived from regression analysis, Bloomfield and Carroll developed a set of lane-keeping and speed-control measures.[14] They showed how to determine two linear equations. The first of these is a lane-keeping equation that represents the line of best fit for a series of points that indicate the offset of the center of a vehicle from the center of the lane, as the vehicle travels along the freeway. The second is a speed-control equation that represents the line of best fit for a second series of points that indicate the velocity of vehicle, as it travels along the freeway.

The lane-keeping equation describes the position of the vehicle relative to the center of the lane at a given time. It indicates how far the vehicle is offset to the left, or right, of the center line of the lane. It also shows whether the vehicle is veering to the left or to the right or is traveling parallel to the lane throughout the series of points. The variability of the actual track of the vehicle around this line of best fit is used, along with the number of crossings of the direction of travel (or line of best fit), to indicate the stability of the driver in maintaining the track of the vehicle. In the current experiment, data were collected at a rate of 30 Hz, so that, as the vehicle traveled along a straight road segment, the track of the vehicle could be used to determine the position of the center of the vehicle relative to a series of perpendicular lines drawn at 1/30-s intervals.

Bloomfield and Carroll assume that the series of positions can be described by the following linear equation:

$$p = a_{lk} - b_{lk}x \qquad (1)$$

where:

- p — is the point (representing the center of the driver's vehicle) at which the line of best fit crosses the perpendicular across the lane after the vehicle has traveled distance x.
- x — is the distance traveled in the lane by the vehicle.
- a_{lk} — is the point at which the line of best fit crosses the perpendicular at the start of the straight road segment.
- b_{lk} — is the gradient of the line of best fit—it is essentially the steering drift.

The series of positions of the center of the vehicle is unlikely to fall exactly on a straight line. However, since in comparison to the 3.66-m (12-ft) width of the lane, the vehicle will travel along what is, relatively speaking, a very long, straight road segment, it is not unreasonable to assume that the series of positions can be described by a linear equation. Because the equation suggested by Bloomfield and Carroll is a linear regression equation, the line of best fit of this equation can be calculated using the method of least squares. Using the method of least squares, which minimizes the error in predicting p from x, the terms a_{lk} and b_{lk} are calculated as follows:

$$b_{lk} = \frac{\sum xp - \frac{(\sum x)(\sum p)}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}} \qquad (2)$$

where n is the number of data points obtained while the vehicle travels distance x, and

$$a_{lk} = \frac{1}{n}\left(\sum p - b_{lk} \sum x\right) \qquad (3)$$

In addition, the variability in b_{lk}—the residual standard deviation—can be used as an estimate of I_{lk}, the steering instability. I_{lk} provides an estimate of the variability in steering that occurs when the driver is attempting to maintain a straight course along the line of best fit. It is given by the equation:

$$I_{lk} = \sqrt{\left[\sum p^2 - \frac{(\sum p)^2}{n} - \frac{\left\{\sum xp - \frac{(\sum x)(\sum p)}{n}\right\}^2}{\sum x^2 - \frac{(\sum x)^2}{n}}\right] \div (n-2)} \qquad (4)$$

Equations 1 and 2 define the position of a vehicle in a straight road segment; equation 3 gives information on steering drift across the lane (if there is any); and equation 4, along with the number of crossings of the direction of travel (or steering oscillations), provides a measure of the smoothness or stability of the ride.

If there were to be a radical change in the direction of the vehicle—and the most radical change that could occur while the vehicle remains in lane would occur if, for example, the vehicle first veered from the extreme right of the lane to the extreme left, then changed direction and veered from the extreme left back to the extreme right of the lane—then, the measures would indicate the radical change, since the steering instability would be relatively large but there would be only two steering oscillations.

The current experiment explored the driving performance of drivers while they were driving on straight and curved segments of expressway both before and after they had experienced traveling under automated control. Bloomfield and Carroll also demonstrate that it is possible to use this linear equation to describe the track of vehicle traveling around a horizontal curve as long as the position of the vehicle in the lane is determined relative to the cross-section of the lane.(14) When the road is curved and the position of the vehicle in the lane is determined relative to the cross-section of the lane, then at each moment, the position of the vehicle will be expressed relative to a line that is perpendicular to the tangent of the curve. In the current experiment, data were collected at a rate of 30 Hz. As a result, around every curve, there were series of tangents at 1/30-s intervals—each with a cross-sectional line that was perpendicular to it. The points at which the track of the vehicle intersected those cross-sectional lines, spaced 1/30-s apart, constituted the lane-position data.

To determine how the lateral position of the vehicle across the lane varies as it travels around a curve, the series of cross-sectional lines are considered together. Since the data were not collected continuously, but rather at intervals that were 1/30-s apart, there are segments of roadway between the cross-sectional lines where data were not collected, Note this is true whether the road is curved or straight. On a straight road, the segments where data are not collected are rectangular; on a curved road they are wedge-shaped. In either case, because the segments are so small when the data rate is as high as it was in this experiment, they can be ignored for purposes of statistical analysis. Because this is true, it does not matter for the analysis whether the roadway was straight or curved—a *linear* regression can be applied to the series of points indicating the position of the vehicle in the lane for both situations Therefore, the set of equations presented above could be used to derive the values of the lane-keeping and speed-control measures from the data collected in the current experiment.

A set of equations similar to those used to describe lane-keeping performance can be used to describe the driver's ability to control the speed of the vehicle. In this case, there are two speed control measures—the first is a measure of the velocity at any instant, the other a measure of whether the velocity is drifting higher or lower—and a measure of the stability of speed control. The speed-control stability measure can be used with the number of steering oscillations, i.e., the number of velocity reversals across the line of best fit (or velocity maintenance line). The equations used in this case differ in that p, a_{lk}, b_{lk}, and I_{lk} in equations 1, 2, 3, and 4 are replaced by v,

a_{sc}, b_{sc}, *and* I_{sc}, respectively, in equations 5, 6, 7, and 8. Equations 5, 6, and 7 provide a description of how well the driver maintains velocity, while equation 8 is a measure of smoothness or stability in maintaining velocity. These equations are presented below:

$$v = a_{sc} + b_{sc}x \tag{5}$$

$$b_{sc} = \frac{\sum xv - \frac{(\sum x)(\sum v)}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}} \tag{6}$$

$$a_{sc} = \frac{1}{n}(\sum v - b_{sc}\sum x) \tag{7}$$

$$I_{sc} = \sqrt{[\sum v^2 - \frac{(\sum v)^2}{n} - \frac{\{\sum xv - \frac{(\sum x)(\sum v)}{n}\}^2}{\sum x^2 - \frac{(\sum x)^2}{n}}] \div (n-2)} \tag{8}$$

where:

- v is the velocity, indicated by the line of best fit, after the vehicle has traveled distance x.
- a_{sc} is the point at which the line of best fit intercepts the velocity axis at the start of the straight road segment.
- b_{sc} is the gradient of the line. If b_{sc} equals zero, the vehicle is traveling at constant velocity; if b_{sc} is positive, the velocity of the vehicle is gradually increasing; and if b_{sc} is negative, velocity is gradually decreasing.
- I_{sc} is the instability in velocity maintenance. It is an estimate of the extent of the velocity fluctuations that occur when the driver is attempting to maintain a chosen velocity.