Risk Assessment of Elderly Drivers at Intersections: Statistical Modeling

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Advances in medicine and health care have caused an increase in the average life expectancy. This, along with the high birth rate after World War II, has caused an increase in the number of drivers in older age groups. Previous studies have shown that the elderly (defined herein as 65 years and older) are involved in a high percentage of accidents at intersections. Because of the continuous increase in the number of elderly drivers on the roads, it is also highly likely that the number of accidents involving the elderly at intersections will continue to increase, unless countermeasures that will reduce this high rate of intersection accidents are identified and implemented. This paper presents results obtained from a study which had an overall objective to identify intersection design and operation parameters that significantly affect the accident involvement of the elderly and thereby develop guidelines to reduce their accident involvement. Statistical models were developed relating the risk of accident involvement to the traffic and geometric characteristics of the intersection. The primary conclusions are as follows: (a) the elderly are more prone to perform a traffic violation when it is necessary for them to yield to opposing traffic compared with drivers of other age groups; (b) the provision of a protected left-turn phase with left-turn lanes will help in reducing the accident rates of the elderly at signalized intersections; and (c) longer amber times will be beneficial to the elderly.

Over the years there has been an increase in the average life expectancy of individuals because of advances in health care and medicine. There has also been an increase in the percentage of older drivers. This trend is expected to continue at least until the middle of the next century (*1*).

Existing data suggest that the crash risk for the elderly is relatively higher than that for the average person. It has been shown that when the amount of travel is taken as the exposure for calculating the risk, the risk starts increasing at approximately the age of 50 (*2*). Similar results have been obtained when fatal accidents were considered (*3*). These statistics indicate that, considering the increase in the number of elderly drivers and their higher risk of accident involvement, the number of accidents involving the elderly will increase unless suitable countermeasures are taken.

Past studies have shown that a high percentage of accidents involving the elderly occur at intersections (*4,5*). However, very few studies of the specific problem that elderly drivers face at intersections have been carried out. Hence, this study concentrates on the impact of specific traffic and geometric factors of intersections on the risk of accident involvement of the elderly.

Intersection design and operation parameters that significantly affect the accident involvement of elderly drivers at intersections were identified, and algorithms that can be used to assess the crash risk of the elderly were developed. The scope was limited to city intersections in Virginia. The specific objectives were

- To identify a suitable way of expressing the risk of accident involvement for elderly drivers,
- To determine mathematical relationships between the crash risk of elderly drivers and significant traffic and geometric characteristics, and
- To identify changes in design and operation parameters that will enhance the safety of the elderly driver.

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COMPILATION OF DATA

Accident Data

The analysis was based on intersection accidents that occurred in cities in the commonwealth of Virginia. Unfortunately, the data on accidents occurring in these cities are not available in a standard computer form. They are available in police accident report forms maintained by the Virginia Department of Motor Vehicles. Police accident reports for intersection accidents involving drivers 50 and older were therefore obtained for four randomly selected cities: Virginia Beach, Roanoke, Lynchburg, and Fredericksburg. Relevant accident information from these accident records was then coded into a computer file. The coded accident data base consisted of approximately 7,000 intersection accidents involving drivers 50 and older in these four cities from 1986 to 1988.

Intersection Traffic and Geometric Data

It was necessary to obtain the specific traffic and geometric data for each intersection selected in the accident data base for the cities, because this information was not included in the police accident reports. This data base was obtained from the answers to questionnaires for each intersection that were sent to the appropriate city engineers. The following information was requested from the engineers:

1. Type of intersection (cross, T, etc.),
2. Traffic control (signal, stop-controlled),
3. Traffic volumes (through volumes, turning volumes),
4. Amber time,
5. Total number of lanes,
6. Approach width,

7. Presence or absence of right-turn lanes,
8. Presence or absence of left-turn lanes,
9. Divided or undivided,
10. Channelized or unchannelized, and
11. Type of left-turn control (protected, permissive, and protected and permissive).

Questionnaires for about 100 intersections were sent to the city engineers, but complete geometric data were available for only 50 intersections.

Risk of Accident Involvement of the Elderly

The conventional way of expressing risk at intersections based on traffic volumes cannot be used for different age groups because of the lack of adequate data on actual volume distribution by age group. It is therefore necessary to use an alternative definition of risk when comparing age groups.

In this study, risk is expressed in terms of involvement ratio, which is defined as the ratio of the number of accidents attributed to drivers in a given age group to the number of accidents not attributed to drivers in that same age group (*6*). In this report, the responsibility of the driver in an accident is based on the occurrence of a traffic violation, which is coded as a driver action. Hence, in this paper, the involvement ratio for any age group is defined as the ratio of the number of accident involvements in which there was a traffic violation by a given age group and the total number of accident involvements in which there was no traffic violation.

One assumption is that the police officer who assigns the responsibility for the accident is unbiased with respect to age. McKelvey et al. tested this by analyzing the data only for right-angle crashes and comparing the results with those for other crashes. The involvement ratios were quite similar. Because responsibility can be more directly assigned for right-angle crashes, it was concluded that the variation in involvement ratios over age cannot be explained by the bias of the police officer (*7*).

STATISTICAL MODELING

In the modeling task, mathematical relationships were developed between the risk of accident involvement and a set of independent variables considered to be related to the accident. Models were developed only for cross-signalized intersections because sufficient data were not available for other types of intersections. Separate models were developed for drivers between 50 and 64 and for drivers 65 and older.

Models using the involvement ratio as the dependent variable and models using the probability of violation as the dependent variable were developed. In the former case, linear models were developed relating the dependent variable to the set of independent variables. In the latter case, logit models were developed.

The following accident-related variables were considered for the statistical modeling:

- PE—percentage of peak-hour left-turn volume with permissive phasing and without left-turn lane;
- APE—percentage of 24-hr left-turn volume with permissive phasing and without left-turn lane;
- PEL—percentage of peak-hour left-turn volume with permissive phasing and left-turn lane;
- APEL—percentage of 24-hr left-turn volume with permissive phasing and left-turn lane;
- PPL—percentage of peak-hour left-turn volume with protected/permissive phasing and left-turn lane;
- APPL—percentage of 24-hr left-turn volume with protected/permissive phasing and left-turn lane;
- PRL—percentage of peak-hour left-turn volume with protected phasing and left-turn lane;
- APRL—percentage of 24-hr left-turn volume with protected phasing and left-turn lane;
- AMB—average amber time in the four approaches;
- SPAMB—average value of the ratio of speed limit amber time in the four approaches;
- RTV—right-turn peak-hour volume as a percentage of peak-hour approach volume;
- ARTV—right-turn 24-hr volume as a percentage of AADT;
- RVR—percentage of right-turn peak-hour volume with right-turn lane;
- ARVR—percentage of right-turn 24-hr volume with right-turn lane;
- LFV—left-turn peak-hour volume as a percentage of peak-hour approach volume;
- ALFV—left-turn 24-hr volume as a percentage of AADT;
- PKLAN—approach peak-hour volume divided by number of lanes;
- AADAN—AADT divided by number of lanes;
- PKVOL—approach peak-hour volume; and
- AADT—annual average daily traffic.

By definition,

$$PE + PEL + PPL + PRL = 100 \text{ and}$$

$$APE + APEL + APPL + APRL = 100.$$

Initially, two more variables (lane width and presence or absence of right turn on red) were also considered in the statistical modeling. It was found, however, that all intersections considered for the final modeling had 12-ft lanes and all permitted right turn on red. Hence, these two variables were dropped from the modeling.

Criteria for Model Selection

Various criteria have been used in the past to select the best model. These include multiple correlation, adjusted multiple correlation, and maximum likelihood. In this study, the best model was selected based on Akaike's information criteria (AIC) (*8*). AIC for any model can be expressed as follows:

$$AIC = -2 \log L(Lk) + 2k \quad (1)$$

where $L(Lk)$ is Log*e* (maximized likelihood), and k is the number of parameter estimates.

The first term represents the badness of fit, whereas the second term corrects for the complexity of the model. The best model is the one with the least AIC value. A complete derivation of the AIC has been provided by Bozdogan (*9*).

Linear Models

Linear models were developed using the involvement ratio as the dependent variable. Multiple linear regression was performed using the PROC RSQUARE module of SAS. The PROC RSQUARE module provides the best model at each level based on the model with the highest R^2-value, which is also the model with the least AIC. From the best model at each level, the best overall model was selected based on the least AIC value. Models were developed for the two age groups using peak hour as well as AADTs.

Model for 50–64 Age Group Using Peak-Hour Volumes

The model with the least AIC was a four-variable model, which is given as follows:

$$Y = -0.3587 - 0.00576\ \text{PRL} + 0.015353\ \text{PE} + 0.041383\ \text{LFV} + 0.001198\ \text{PKLAN}$$
$$\text{AIC} = -30.79,\ R^2 = 0.75 \qquad (2)$$

where Y is the involvement ratio for the 50–64 age group.

This model shows that an increase in PE, LFV, or PKLAN causes an increase in the involvement ratio, whereas an increase in PRL reduces the involvement ratio. Sensitivity analysis was performed by considering an increase of 10 percent of each independent variable over the observed mean values. The involvement ratio corresponding to the mean values of the independent variables is equal to 0.92. An increase of 10 percent over the mean value of LFV increases Y to 0.99, whereas an increase of 10 percent over the mean value of PKLAN increases Y to 0.97. In order to study the effect of left-turn phasing, three cases were considered: PE equal to 100, PEL equal to 100, and PRL equal to 100. When PE is equal to 100, the involvement ratio is equal to 2.2. When PEL is equal to 100 (i.e., PE = 0, PPL = 0, PRL = 0), the involvement ratio reduces to a value of 0.7. When PRL is equal to 100, the involvement ratio reduces further to 0.3. This shows that the provision of left-turn lanes and protected left-turn phases will reduce the involvement ratio of the 50–64 age group at the intersection.

Model for 65-and-Older Age Group Using Peak-Hour Volumes

The model was the least AIC value was a four-variable model, which is given as follows:

$$Y = -10.6619 + 0.040164\ \text{PE} + 0.033648\ \text{PEL} + 0.85830\ \text{SPAMB} + 0.13986\ \text{LFV} \qquad \text{AIC} = 9.904,\ R^2 = 0.56 \qquad (3)$$

where Y is the involvement ratio for the 65-and-above age group.

This model shows that an increase in PE, PEL, or SPAMB produces an increase in the involvement ratio. This model indicates that although the involvement ratio tends to increase when the percentage of left-turn volume using a permissive phase increases, this effect is reduced when a left-turn lane is provided. The involvement ratio corresponding to the mean values of the independent variables is equal to 1.79. An increase of 10 percent in LFV increased the involvement ratio to 2.03, whereas an increase of 10 percent in SPAMB increased the involvement ratio to 2.6. In order to study the effect of left-turn phasing, three cases were considered: PE equal to 100, PEL equal to 100, and PRL equal to 100. When PE is equal to 100, the involvement ratio is equal to 4.06. When PEL is equal to 100, the involvement ratio is reduced to 3.4. When PRL is equal to 100 (i.e., PE = 0, PEL = 0, PPL = 0), the involvement ratio drops to almost zero.

This model suggests that the involvement ratio of the elderly will increase as the percentage of the left-turn volume increases, but this increase will be reduced if left-turn protected phasing with left-turn lanes is provided for a high percentage of left-turn volumes. Another variable that seems to have a significant effect on the involvement ratio of the elderly is the average value of the ratio of the speed limit and the amber time at all approaches. Because the higher the amber time, the lower the value of the SPAMB for any given speed limit, the model suggests that longer amber times will aid in reducing the involvement ratio of the elderly at signalized intersections. This suggests that the amber period of 3 to 5 sec now used at signalized intersections may not be adequate for the elderly. Also, the reduction in their risk when a left-turn lane is provided on approaches with a permissive phase is less than that for the 50–64 age group. Figure 1 shows the variation of involvement ratio with PE and LFV.

Model for 50–64 Age Group Using 24-hr Volumes

The model with the least AIC was a three-variable model, which is given as follows:

$$Y = 0.2098 + 0.01253\ \text{APE} - 0.00546\ \text{APRL} + 0.04208\ \text{ALFV} \qquad \text{AIC} = -28.02,$$
$$R^2 = 0.73 \qquad (4)$$

This model shows that an increase in APE or ALFV produces an increase in the involvement ratio, whereas an increase in APRL causes a reduction in the involvement ratio. The involvement ratio corresponding to the mean values of the independent variables was 0.904. An increase of 10 percent in the value of ALFV increases the involvement ratio to 0.97. In order to study the effect of left-turn phasing, three cases were considered: APE equal to 100, APEL equal to 100, and APRL equal to 100. When APE is equal to 100, the involvement ratio is equal to 2.14. When APEL is equal to 100 (i.e., APE = 0, APPL = 0, APRL = 0), the involvement ratio is reduced to 0.88. When APRL is equal to 100, the involvement ratio is reduced further to 0.34. These results are

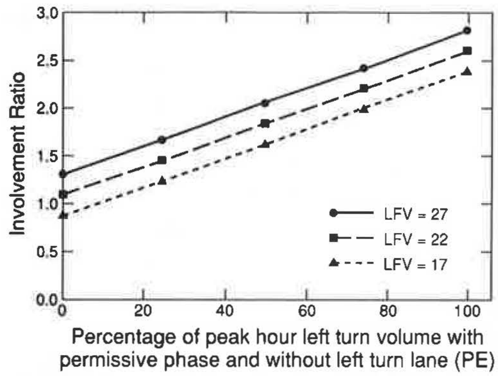

FIGURE 1 Effect of PE and LFV on involvement ratio of 50–64 age group using peak-hour volumes.

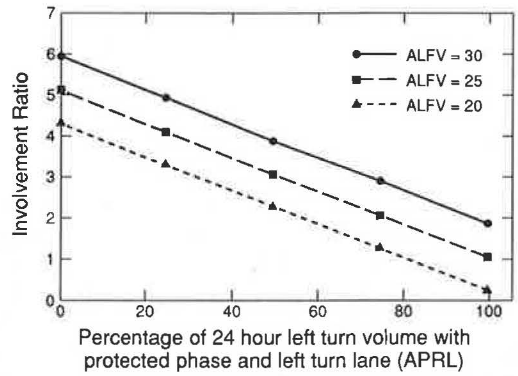

FIGURE 2 Effect of APRL and ALFV on involvement ratio of 65-and-above age group, using 24-hr volumes.

similar to those obtained for the model of peak-hour volumes (Equation 2) in that the provision of protected phasing left-turn lanes will reduce the involvement ratio for the 50–64 age group.

Model for 65-and-Older Age Group Using 24-hr Volumes

The least AIC in this case was obtained for a four-variable model, which is given as:

$$Y = -6.6640 + 0.77154\,\text{SPAMB} + 0.16515\,\text{ALFV} - 0.04063\,\text{APR} - 0.030596\,\text{APPL}$$
$$\text{AIC} = 6.704, R^2 = 0.65 \quad (5)$$

This model shows that an increase in ALFV or SPAMB causes an increase in the involvement ratio, whereas an increase in APRL or APPL causes a decrease in the involvement ratio. The involvement ratio corresponding to the mean values of the independent variables was equal to 1.6. An increase of 10 percent in the value of ALFV increases the involvement ratio to 1.87, and an increase of 10 percent in the value of SPAMB increases the involvement ratio to 2.35. In order to study the effect of left-turn phasing, three cases were considered: APEL equal to 100, APPL equal to 100, and APRL equal to 100. When APEL is equal to 100 (i.e., APE = 0, APPL = 0, APRL = 0), the involvement ratio is equal to 3.46. When APRL is equal to 100, the involvement ratio is reduced to 0. When APPL is equal to 100, the involvement ratio is 0.4. These results are also consistent with those obtained for the model using peak-hour volumes (Equation 3) in that the provision of a protected left-turn phase with left lanes and longer amber times will reduce the involvement ratio of the elderly at signalized intersections. Also, the use of 24-hr volumes seems to provide a better fit (AIC = 6.7, R^2 = 0.65) compared to that obtained for peak-hour volumes (AIC = 9.0, R^2 = 0.56). This may be due to the fact that the elderly travel less during the peak time than other age groups. Figure 2 shows the variation of the involvement ratio with changes in APRL and ALFV.

Logistic Models

As already mentioned, the logistic model was used to relate the probability of violation to the independent variables. The logistic model is based on the binomial theorem, where there are only two possible values for the response (dependent) variable: 1 denoting a success and 0 denoting a failure. In our case, the occurrence of a traffic violation was considered a success and coded as 1, and the nonoccurrence of a traffic violation was considered a failure and coded as 0. The logit model predicts the probability of success, which in our case is the probability of the occurrence of a violation. In a logit model, the relationship between the dependent and independent variables is expressed in this form:

$$P = 1/(1 + e^{-AX}) \quad (6)$$

where P is the probability of success (violation), and AX is defined as $AX = A_1X_1 + A_2X_2 + \ldots + A_nX_n$, where $X_1 \ldots X_n$ are the independent variables.

Logistic regression was performed using the PROC LOGIST module in SAS. A forward as well as a backward stepwise procedure was adopted, and the best model was determined based on the AIC values.

Model for 50–64 Age Group Using Peak-Hour Volumes

The least AIC in this case was obtained for a four-variable model, which is given as follows:

$$AX = -2.49806 + 0.02114\ \text{PE} - 0.009007\ \text{PRL} + 0.00195\ \text{PKLAN} + 0.078203\ \text{LFV} \quad \text{AIC} = 201.29 \quad (7)$$

This model shows that an increase in PE, PKLAN, or LFV results in an increase in the probability of violation, whereas an increase in PRL causes a reduction in the probability of violation. The probability of violation corresponding to the mean values of the independent variables is equal to .436. An increase of 10 percent in the mean value of LFV increases the probability of violation to .467, whereas an increase of 10 percent in the mean value of PKLAN increases the probability of violation to .457. To study the effect of change in the left-turn phasing, three cases were considered: PE equal to 100, PEL equal to 100, and PRL equal to 100. When PE is equal to 100 percent, the probability of violation is .846. When PEL is equal to 100 percent (i.e., PE = 0, PRL = 0, PPL = 0), the probability of violation is reduced to .40. Also, when PRL is equal to 100 percent, the probability of violation is reduced to .213. These results are also consistent with those given in Equations 2 and 4 in that the probability of violation increases with an increase in left-turn volumes, but this effect is reduced when left-turn lanes and protected phases are provided.

Model for 65-and-Older Age Group Using Peak-Hour Volumes

The least AIC in this case was obtained for a two-variable model, which is given as follows:

$$AX = -2.36491 - 0.0138101 \text{ PRL} + 0.32884 \text{ SPAMB} \qquad \text{AIC} = 134.24 \tag{8}$$

This model shows that an increase in SPAMB produces an increase in the probability of violation, whereas an increase in PRL causes a reduction in the probability of violation. The probability of violation corresponding to the mean values of the independent variables is .61. An increase of 10 percent over the mean value of SPAMB increases the probability to .68. If PRL is changed from its mean value to 0, the involvement ratio increases to 0.702. When PRL is increased to 100, the probability is reduced to .372. These results are consistent with those obtained with Equations 3 and 5. Figure 3 illustrates the variation of the probability of violation with PRL and SPAMB.

Model for 50–64 Age Group Using 24-hr Volumes

The least AIC in this case was obtained for a three-variable model, which is given as follows:

$$AX = -1.42536 - 0.00802 \text{ APRL} + 0.07475 \text{ ALFV} + 0.01475 \text{ APE} \qquad \text{AIC} = 201.44 \tag{9}$$

This model shows that an increase in ALFV or APE causes an increase in the probability of violation, whereas an increase in APRL produces a reduction in the probability of violation. The probability of violation corresponding to the mean values of the independent variables is .46. An increase of 10 percent over the mean value of ALFV increases the probability of violation to .49. When the value of APE increases from its mean value to 100, the probability of violation increases to .776; but, when both APE and APRL are equal to zero (APEL + APPL = 100), the probability of violation is reduced to .44. When APRL is increased to 100, the probability of violation is reduced to .263. These results are also consistent with those obtained previously.

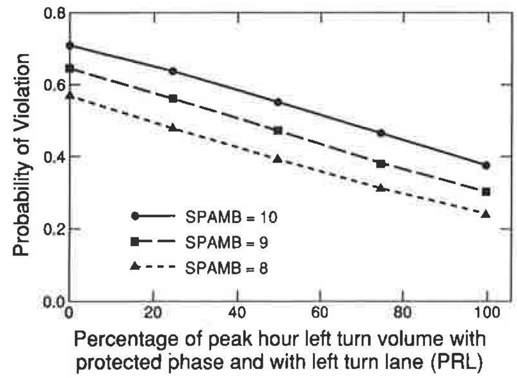

FIGURE 3 Effect of PRL and SPAMB on probability of violation for 65-and-above age group, using peak-hour volumes.

Model for 65-and-Above Age Group Using 24-Hour Volumes

The least AIC in this case was obtained for a three-variable model, which is given as follows:

$$AX = -0.41702 - 0.015789 \text{ APRL} - 0.015116 \text{ APPL} + 0.096615 \text{ ALFV} \qquad \text{AIC} = 133.38 \tag{10}$$

This model shows that an increase in ALFV produces an increase in the probability of violation, whereas an increase in APRL or APPL causes a reduction in the probability of violation. The probability of violation corresponding to the mean values of the independent variables is .606. A 10 percent increase in ALFV over its mean value was found to increase the probability to .642. Increasing APRL from its mean value to 100 decreases the probability to .389. Increasing the value of APPL from its mean value to 100 decreases the probability of violation to .406. These results are also consistent with those obtained using the other models for the 65-and-older age groups. Figure 4 illustrates the effect of APRL and ALFV on the probability of violation.

SUMMARY AND CONCLUSIONS

The complex problem of assessing the risk of elderly drivers was investigated in this report. A detailed study was conducted by investigating the effect of traffic and geometric variables using statistical modeling.

The models developed can be used to evaluate the effectiveness of specific countermeasures, such as providing a left-turn lane or a protected left-turn phase, or both, for different traffic volumes at intersections. The models can therefore be used to evaluate the feasibility of implementing these countermeasures.

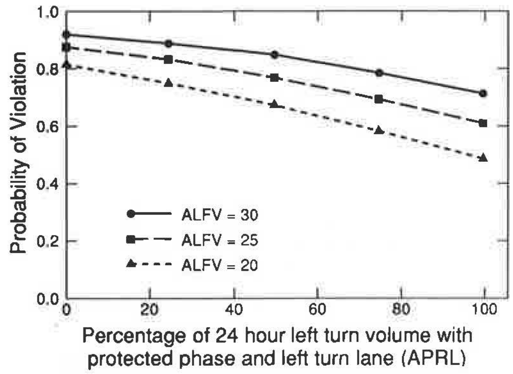

FIGURE 4 Effect of APRL and ALFV on probability of violation for 65-and-above age group, using 24-hr volumes.

The following conclusions can be made from the results of the statistical modeling:

1. An increase in the percentage of left-turn volume at an intersection increases the involvement ratio for the elderly. This effect is, however, reduced by the provision of a protected phase with left-turn lanes for a large percentage of left-turn volumes.
2. An increase in amber time for a given speed limit reduces the involvement ratio for the elderly. This implies that the amber period of 3 to 5 sec is probably not sufficient for the elderly because of their longer reaction times.
3. The involvement ratio of the elderly is much more dependent on the AADT than on the peak-hour volumes, probably because the elderly travel less during peak hours than other age groups.

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