Applications of Accident Prediction Models

MICHAEL YIU-KUEN LAU, ADOLF D. MAY, AND RICHARD N. SMITH

One of the current methods used to overcome “regression-to-mean” problems in safety studies is to employ a combination of accident histories and accident prediction model estimates for estimating future safety. Besides applications in before-and-after studies, there is also a wide range of applications of accident prediction models (e.g., accident surveillance, network simulation and optimization studies); and they are the focus of this paper. The prediction model used in this paper is a three-level prediction procedure being planned for implementation by the California Department of Transportation (CALTRANS). This staged procedure also allows different applications to be made for a wide variety of projects with different input and output requirements. It is shown that the three-level prediction procedure provides a very detailed, comprehensive, and yet flexible framework for safety evaluations of highway intersections. Meanwhile, one can also appreciate from the discussion that great care should be taken in using those estimates for different purposes. It is also apparent that as accident prediction models are becoming more sophisticated and important to safety studies, a close link should be developed between people who are developing those models and those who are applying them in practice, so that maximum benefits can be obtained.

This paper is based on a 2-yr project sponsored by the California Department of Transportation (CALTRANS) and Federal Highway Administration (FHWA) as shown in Figure 1. Some applications of accident prediction models with numerical illustrations are described. A paper covering the development of the injury accident prediction models used in this paper was presented at the 67th Annual Meeting of the Transportation Research Board (1) (see Figure 1). A summary of the development of the injury, property-damage-only (PDO), and fatal accident models used is included later in this paper for easy and quick reading. This paper concentrates on applications of accident prediction models, an adjustment procedure for underreporting level of PDO accidents, and highlights of the PDO and fatal accident models that were not discussed in the earlier work (1). Further details of the development of the models can be found elsewhere (1,2).

In the past, accident studies have concentrated mainly on before-and-after studies, which are aimed at finding the “treatment effect” of improvement measures, and have placed relatively little emphasis on accident prediction models. One of the causes of such a trend may have been the belief that accidents are accidents—they are difficult to predict. Unfortunately, most of the results of before-and-after studies have been found to be too optimistic as a result of the way the entities are selected for improvement studies. Specifically, the entities are selected on the basis of their recent poor accident performances, and it is very likely that those entities will revert to the “mean” even though no treatment is applied to them. One of the current methods used to overcome “regression-to-mean” problems is to use a combination of accident history and group estimate for estimating future safety (3). The group estimates here refer to accident prediction model estimates, and they turn out to be essential elements of this new approach. A similar concern can also be found in a paper by Elvik (4). Besides before-and-after studies, there is also a wide range of applications of accident prediction models (e.g., accident surveillance, network simulation, and optimization studies), and they are the focus of this paper.

THE ACCIDENT PREDICTION MODELS USED

The accident prediction models used are derived through an intuitive methodology based on the Traffic Accident Surveillance and Analysis System (TASAS) in California. A fairly new grouping and classifying technique called Classification and Regression Trees (CART) (5) was used as a building block for developing accident prediction models. The proposed methodology includes a three-level prediction procedure with a “tree” structure for easy interpretation and applications and an adjustment procedure for different reporting levels of PDO accidents in different police jurisdictions. This staged procedure also allows different applications to be made for a wide variety of projects with different input and output requirements.

Classification of Accidents and Selection of Response Variable

Accidents may be classified by type of collision, turning movement conflicts, severity, or a wide variety of other measures. Classification of accidents for this study was confined to injury, fatal, and PDO-type accidents. Advantages of the severity classification include its easy comprehension and simple translation into monetary terms, required by most economic and feasibility analyses. The disadvantages of this classification scheme include inadequacy in reflecting the actual process of collisions and the concept of traffic conflicts.

The selection of a response variable for injury, PDO, and fatal accidents is a very important step in the process because the response variable largely determines the final model. The
Adjustment for Different Reporting Levels

Underreporting of accidents (especially of PDO accidents) is a very common problem. It was found in Smith's study (6) that the overall reporting level of PDO accidents was about 38 percent. There was also a difference in underreporting levels in different police jurisdictions. An attempt was made to derive a factor for adjusting the number of reported PDO accidents without the need for collecting additional information from police jurisdictions by interviews or surveys. A proposed procedure is shown in Figure 2. An example of the application of the procedure can be found in the section called "Level II Applications." No attempts have been made to adjust the number of reported injury and fatal accidents because of the constraints of the study and the high reporting levels of injury (about 90 percent) and fatal (about 100 percent) accidents (6).

Generation of Base Model—Level I

Instead of putting some forms of the traffic intensity variable in the denominator of the response variable, a base model was built with injury or PDO accidents per year as the response variable and traffic intensity, expressed in millions of vehicles entering the intersection per year from all approaches, as a predictor variable. One of the advantages of this approach is that it allows researchers to see the relationship between the two variables in an undistorted manner, as in a scatter plot. Based on the untransformed information on a graph, one can try different functional forms to model the relationship between the two variables. Estimates of the parameters can be obtained using such techniques as least square, maximum likelihood, and so forth. The base model so obtained is referred to as Level I prediction. A slightly different approach was adopted for fatal accidents and is described briefly in the section headed "Fatal Accidents" because a reasonable relationship cannot be established between the number of fatal accidents and traffic intensity.

Grouping Intersections by CART—Level II

Further information, such as design, control, proportion of cross street traffic, and environmental features of the intersections, is also considered as other major factors affecting the safety of intersections. The importance of these factors can sometimes be reflected in the large variations found in most scatter plots between the number of accidents and traffic intensity. One possible approach is to analyze the residuals of the base model on the basis of other intersection characteristics. In other words, those intersections with similar characteristics that have higher or lower accident records than other intersections in general can be grouped together. The residual is defined as the difference between the observed value and predicted value by the base model. As for the fatal accident model, the number of fatal accidents, but not the residual, can be used as the response variable for grouping by CART. An immediate question arises as to how many groups should be selected to represent high/low accident risk intersections. Extreme solutions include 1 and n groups, where n is the number of intersections in the data base. With a single group, it is equivalent to the base model and, therefore, is not interesting, because some understanding of the design factors that tend to affect the safety of intersections is desirable. When there are n groups, it may indicate that the given characteristics of the intersections cannot be used to produce a grouping that can reflect similar patterns. Also, with n groups there is no way to identify those intersections that are "out of line" for purposes of accident surveillance. So engineering judgment and a technique to group intersections with error measures would be very important to the process. The rule of determining whether a node is a terminal node in the CART procedure is quite complex and related to the issue of tree pruning. The process of pruning limbs from a full-grown tree makes CART different from all other tree-structured techniques, such as THAID (7). The other techniques keep splitting a node until there is no further improvement. The advantage of the CART approach is that it allows an average split to occur, so that it can set up for some good splits further down the tree. An average split is a split that does not provide
a large improvement in prediction error measures. The CART program has demonstrated potential in many medical and military fields. At the University of San Diego Medical Center, CART is used to assist doctors in developing the diagnosis and prognosis of heart attack patients. In the military field, it is used to classify ship types (e.g., oil tankers versus warships) from radar range profiles.

The CART program is used to analyze the residuals of the base model of injury and PDO accidents and to group intersections with similar accident patterns. The refinement of estimates by grouping intersections based on other intersection characteristics is referred to as Level II prediction. In the case of fatal accidents, the response variable would be the number of fatal accidents per year because, unlike injury or PDO accidents, a base model could not be established for fatal accidents. The predictor variables used in this level of analysis of fatal accidents also include main and side street ADTs as they have not been used in Level I analysis. The prediction trees obtained are shown in Figures 3, 4, and 5 for injury, PDO, and fatal accidents, respectively. Details of the development of the trees can be found elsewhere (2). However, applications of these models or trees with numerical illustrations can be found later in this paper.

Another unique feature of CART is the concept of prediction errors. For example, in regression context, one would usually view the coefficient of determination ($R^2$) as a yardstick of prediction accuracy. One obvious disadvantage of this approach is that one could artificially increase this value simply by increasing the number of predictor variables or parameters in a model; the same data set is used to estimate model parameters and the same data set is used to calculate error measures. Although there are many ad hoc solutions to mitigate this problem, it is obvious that a basic approach is to adopt a concept of prediction accuracy by independent samples, such as test set or cross-validation techniques. Independent data sets are used to estimate model parameters and to calculate prediction errors in both of these methods. An example of a cross-validated relative prediction error ($r(d)$) of 0.90 was found in Figure 3. A relative prediction error of 0.90 implies that CART was able to reduce the prediction error further by about 10 percent. It may look like a marginal improvement; however, remember that it is a "honest" esti-
FIGURE 3  Regression tree for injury accidents by CART.

FIGURE 4  Regression tree for PDO accidents by CART.
Adjustment by Accident History—Level III

The preceding discussions refer to estimates of accident prediction for groups of intersections. In other words, all intersections within a certain group will have an equal estimate. It can be argued that the grouping made was based only on information that was available in the list of predictor variables and that they may not contain all of the factors that affect accident occurrences. As a result, the accident history of individual intersections becomes a very valuable source of information reflecting the safety level of individual intersections. The idea of a linear combination of group estimate and individual accident history, as proposed by Hauer et al. (3), is referred to as Level III in this study; and its applications in evaluating the benefits of safety improvements are discussed in the section on Level III applications and in Figure 6. As a whole, it is believed that this staged procedure (Levels I, II, and III) is more flexible than some other existing methods in that it allows users to have different input requirements for a wide variety of projects while it gives them an opportunity to appreciate the evolvement of their estimates.

TYPES OF APPLICATION OF ACCIDENT PREDICTION MODELS

Applications of accident prediction models can be grouped into the following categories:

1. Large-scale regional transportation planning studies—Level I;
2. Estimate of safety performance of new intersections—Level II;
3. Estimate of safety performance of redesigned intersections—Level II;
4. Network simulation and optimization studies—Level I;
5. Accident surveillance—Level II;
6. Estimate of safety of an existing intersection with accident history—Level III; and
7. Before-and-after studies—Level III.

Although the sections that follow are structured according to Levels I, II, and III, as described earlier, one can see from Figure 7 that this structure also falls into two large subgroups. The first group concerns new or modified intersections, and the second group concerns existing intersections. Before the discussion on applications, there is a numerical illustration of the mechanics of predicting injury, PDO, and fatal accidents.
Numerical Illustration by Sample Intersection

The sample intersection has mainline and cross street ADTs of 49,000 and 10,000, respectively. It is a four-legged intersection with two lanes on each main and cross street approach. It has a multiphase, pretimed signal controller with left turns permitted. A sketch of this intersection and other relevant information is shown in Figure 8. A summary of the predictions made by the models and accident experience from 1979 through 1985 at this intersection is shown in the following table. Detailed calculations for injury, PDO, and fatal accidents can be found elsewhere (2, Tables VII.2, VIII.4, and IX.2, respectively). A brief rundown can also be found in the next section.

<table>
<thead>
<tr>
<th>Predictions</th>
<th>Level I</th>
<th>II</th>
<th>III</th>
<th>Observed Values (1979–1985)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury</td>
<td>4.26*</td>
<td>4.99</td>
<td>5.74</td>
<td>5.86</td>
</tr>
<tr>
<td>PDO</td>
<td>15.68</td>
<td>16.60</td>
<td>17.94</td>
<td>17.97*</td>
</tr>
<tr>
<td>Fatal</td>
<td>0.018</td>
<td>0.057</td>
<td>0.141</td>
<td>0.29</td>
</tr>
</tbody>
</table>

*Unit in number of accidents/year.

Level I Applications

For this level of analysis, only the traffic intensity, expressed in millions of vehicles entering an intersection from all approaches (MVYR), is required for injury and PDO accident models. As expected, the results provide only a crude estimate of the safety of intersections. As for fatal accidents, a bedrock value or constant is used in this level of analysis, as described in the section headed "Fatal Accidents."

Large-Scale Regional Transportation Planning Studies

There are many cases in regional transportation studies in which only information on traffic intensity is available, but crude estimates of the safety of proposed strategies are also required for overall assessments and economical evaluations. For example, in large-scale regional transportation planning studies, in addition to the conventional system measures, such as speed, vehicle-miles of travel, and so forth, such safety measures as number of injury accidents, PDO accidents, and fatal accidents can provide valuable information for cost-effectiveness evaluations.

Injury Accidents

The following equation, which was derived in earlier work (1) for estimating the forecasted number of injury accidents per year (FIACCYR) at an intersection with...
<table>
<thead>
<tr>
<th>New or Modified Intersections</th>
<th>Existing Intersections</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Planning Studies</td>
<td>v) Accident Surveillance</td>
</tr>
<tr>
<td>- Level I</td>
<td>- Level II</td>
</tr>
<tr>
<td>ii) Safety of New Intersection</td>
<td>vi) Safety of Existing Intersection</td>
</tr>
<tr>
<td>- Level II</td>
<td>- Level III</td>
</tr>
<tr>
<td>iii) Safety of Modified</td>
<td>vii) Before- &amp; After</td>
</tr>
<tr>
<td>Intersection</td>
<td>Studies</td>
</tr>
<tr>
<td>- Level II</td>
<td>- Level III</td>
</tr>
<tr>
<td>iv) Network Signal</td>
<td></td>
</tr>
<tr>
<td>Study (Major)</td>
<td></td>
</tr>
<tr>
<td>- Level II</td>
<td></td>
</tr>
</tbody>
</table>

**Intersection Characteristics:**

- MADT = 49000 veh/day (2-way)
- XADT = 10000
- ITYPE = 1 (four legged)
- CTYTYPE = 2 (multiphase pretime signal)
- MTF = 2 (left turn permitted)
- XTF = 2 (left turn permitted)
- MNL = 4 (2 lanes per approach)
- XNL = 1 (2 lanes per approach)
- SPEED = 6 (design speed 50-54 mph)

**PDO Accidents**

Because of different reporting levels of PDO accidents in different jurisdictions, the number of reported PDO accidents must be adjusted, as described earlier, to find the true number of PDO accidents per year. The following equation, from an earlier work (2), for PDO accidents has been constructed by the adjusted number of PDO accidents, so the forecast number of PDO accidents per year (FPDOYR) represents adjusted values:

\[
FPDOYR = RORU \cdot IGR0 \cdot PDOn \cdot IJF \cdot IRJ
\]

To illustrate, the values of main and side street ADTs of an intersection are 49000 and 10000, respectively, making 21.53 million vehicles (MVYR) entering the intersection (= (49000 + 10000) * 365/1000000). When 21.53 is put into the preceding equation, one finds that FIACCCYR is about 4.26 forecasted injury accidents per year. So without further information, 4.26 could be used as the expected number of injury accidents per year at this new intersection for large-scale transportation planning studies.

**PDO Accidents**

Because of different reporting levels of PDO accidents in different jurisdictions, the number of reported PDO accidents must be adjusted, as described earlier, to find the true number of PDO accidents per year. The following equation, from an earlier work (2), for PDO accidents has been constructed by the adjusted number of PDO accidents, so the forecast number of PDO accidents per year (FPDOYR) represents adjusted values:

\[
FPDOYR = RORU \cdot IGR0 \cdot PDOn \cdot IJF \cdot IRJ
\]
FPDOYR = 4.6029 + 0.5142 \times MVYR

Because MVYR equals 21.53, it is found, on the basis of this equation, that FPDOYR is 15.68. This is the same value found in the preceding table; consequently, this value could be used as the expected number of PDO accidents per year at this new intersection in large-scale transportation planning studies.

**Fatal Accidents**  Because the number of fatal accidents per year does not have a strong relationship with the MVYR, an equation like the preceding formula was not constructed. Instead, a concept of system risk was formulated, and a bedrock value of 0.018 fatal accidents per year was used as a Level I estimate to reflect the proportion of fatal accidents that are related to sobriety, drug, or physical impairment (S/D/P) of the people involved in the accident. No such amendment was made to injury and PDO models because the S/D/P problem was found to be applicable only to fatal accidents. Unlike injury and PDO accidents, this Level I estimate should not be used alone because it is just a constant term to be added to the Level II estimate. Of course, the Level II estimate for fatal accidents could be used alone as described in the following sections.

**Level II Applications**

Detailed information, such as design, control, demand, and environmental features of the intersection, is usually required for this level of analysis. Level II estimates are basically refinements of Level I estimates using such information as design, control, and so on. Applications of Level II estimates can include the following categories:

1. Estimate of safety performance of a new intersection;
2. Estimate of safety performance of a redesigned intersection;
3. Network simulation and optimization studies; and
4. Accident surveillance studies.

**Estimate of Safety Performance of New Intersections**

New intersections include intersections that have not been built. Hence, accident histories of these intersections are not available. For example, suppose an intersection is planned and designed to have the same characteristics as the sample intersection shown in Figure 8.

**Injury Accidents**  From Level I analysis, the forecast number of injury accidents per year can be calculated, with a result of about 4.26 accidents. On the basis of Level II analysis and the classification tree for injury accidents as shown in Figure 3, one can see that this intersection belongs to Group 5 of the tree, with an expected mean of positive 0.73. This is the mean of the 492 residuals, as defined in the earlier section on grouping intersections with CART, of the 492 intersections with characteristics under Group 5 of the tree in Figure 3. The characteristics of the intersection are shown in Figure 8. As a result, one should add 0.73 injury accident per year to the Level I estimate of 4.26. In other words, with more information on design, control, and so forth, the Level I estimate could now be refined to 4.99 (= 4.26 + 0.73), which is a more accurate estimate of the expected number of injury accidents per year at an intersection with the characteristics under discussion.

**PDO Accidents**  From Level I analysis, one can get an estimate of 15.68 PDO accidents per year. On the basis of Level II analysis and the tree for PDO accidents as shown in Figure 4, one can see that this intersection falls into Group 5 with a sample mean of positive 0.92. Adding 0.92 and 15.68 results in a Level II estimate of 16.60, and this value could be used as the expected number of PDO accidents per year occurring at an intersection with the characteristics under discussion. Because the reported number of accidents at this intersection in TASAS is 5.56, as appeared in the preceding table, one might wish to "undo" the adjusted 16.60 to the likely reported 5.06 for purposes of comparison. The value 5.06 can be obtained by the equations in Figure 2 and shown again here for illustration.

\[
PDO_y = I_y + 4.5 = 651 + 4.5 = 2925.5
\]

(inside city)

\[
(PDO_y + 1) = PDO_y / (PDO_y + I_y) \\
= 16.60 / (2925.5 + 651) / (656 + 651) \\
= 6.06
\]

\[
PDO_y = 6.06 - 1 = 5.06
\]

**Fatal Accidents**  For Level II analysis and the tree as shown in Figure 5, one can see that this intersection falls into Group 5 (predicted class B, PB) of that tree with a sample mean of 0.039. So the Level II estimate is equal to the summation of 0.018 from Level I and 0.039 from Group 5 of the tree, and this becomes 0.057 fatal accident per year. The same interpretation used for injury and PDO accidents can be applied here as well.

**Estimate of Safety Performance of Redesigned Intersection**

On the basis of the earlier procedure and the trees shown in Figures 3, 4, and 5, one could get some ideas about how an intersection should be redesigned so that the expected number of accidents could be reduced. To put this decision process into proper perspective, let us look at the injury accident tree in Figure 3. It is obvious that if this intersection were changed to a multiphase, fully vehicle actuated signal intersection, there could be a reduction in injury accidents. The new value would be 4.70 (= 4.26 + 0.44) instead of 4.99, as found earlier, because this redesigned intersection would belong to Group 4 of the tree. Of course, this is just a thought exercise because there are other considerations besides safety (e.g., efficiency) that an engineer must take into account when redesigning an intersection. One can also view this as a classic
example of a trade-off between safety and efficiency in an engineering design (more phases implies less efficiency versus a lower number of accidents). Furthermore, any changes in other parts of the network that result from such an improvement should also be considered carefully. Furthermore, there is another issue that should be approached very cautiously when redesigning intersections on the basis of any accident prediction models. Nearly all prediction models are built with a view to derive some associations between some design, control, demand, or other factors and some kind of accident experience. They could not establish a cause-and-effect relationship because a cause-and-effect relationship can be established only if the intersections are selected randomly to receive a cause (treatment) and are observed for its effects (subsequent performance). Unfortunately, this kind of experiment can be very expensive and sometimes politically unacceptable because, in this type of experiment, an engineer needs to implement some potentially good measures at intersections chosen at random and not on the basis of their poor accident records. The baseline here is that, when redesigning an intersection on the basis of accident prediction models, it is important to realize that one's judgment is being placed on some associational relationships and not on real cause-and-effect relationships. A discussion of some ideas about conducting improvement studies using knowledge-based expert systems can be found elsewhere (8).

**Network Simulation and Optimization Studies**

For most network simulation and optimization studies, there are at least two situations one might want to distinguish as far as a safety estimation is concerned. If the study is concerned with intersections that have not been built, or if major changes are likely to occur to these intersections so that their individual accident histories no longer represent their future safety characteristics, then Level II estimates (similar to the procedure in the preceding section) could be used. The Level II estimates could be calculated at all the intersections to form an overall system safety index (e.g., total number of accidents) that could then be combined with the other system efficiency index (e.g., total delay) for overall system optimization. On the other hand, if the study is aimed at optimization of signal timing intervals and not at changes in phase arrangements and the like, one might want to consider the individual accident histories of the intersections to reflect their unique characteristics. Minor changes in signal timing intervals are not likely to change intersection safety characteristics to a large extent. In this case, then, one might want to go to Level III estimates, which are discussed later.

**Accident Surveillance Studies**

The purpose of most accident surveillance studies is to provide an early indication or warning to highway agencies of the past performance of their road elements, such as intersections. With this information, the agencies might want to investigate further those intersections that have been identified as "out of line" with other intersections in their group. The criteria for identifying outliers can be very controversial because one can identify outliers by total accidents or by deviations from the group, a controversy that is not the subject of this study. However, one element that is very important to the process, regardless of what criteria may be adopted in the selection process, is estimation of the safety of the group of intersections to which a particular intersection belongs. A Level II estimate can be used as the group estimate for this purpose because it represents the expected number of injury (or PDO or fatal) accidents per year for the group of intersections to which the intersection belongs.

**Level III Applications**

For this level of analysis, the individual accident history of an intersection is required in addition to the information required in Levels I and II. Level III results represent future safety estimates of existing intersections. These estimates are based on a concept of linear combination of two estimates—individual accident history and group estimate. Hauer and Persaud (3) derived an estimate, \( Z \), based on a linear combination of the two results to predict the safety of an individual intersection using the following equation:

\[
Z = aE[m] + (1 - a)x
\]

where

\[
a = \left(1 + \frac{\text{Var}(m)}{E(m)}\right)^{-1},
\]

\[
m = \text{expected accident statistics}, \quad x = \text{accident count}.
\]

They also suggested that the sample mean \( \bar{x} \) could be used to estimate \( E(m) \) and sample standard deviations(s) could be used to estimate \( \text{Var}(m) \) using the following equations:

\[
E[m] = E(x)
\]

\[
\text{Var}(m) = (s^2 - \bar{x})
\]

Further illustration of this approach and some numerical examples can be found in the section on before-and-after studies and in Figure 6. Main applications of this level of analysis can include the following:

1. To estimate the future safety of an existing intersection when no changes to the intersection are made with an accident history, and
2. To allow before-and-after studies to be conducted when the "regression-to-mean" effect cannot be avoided.

**Estimate of Future Safety of an Existing Intersection with Accident History**

The individual accident history of an intersection can give a picture of the unique characteristics of the intersection that could not be captured by the group or model estimate. The Level III estimate can be used for this purpose, and numerical examples can be found in the sections that follow.

**Injury Accidents** This particular intersection has a history of 5.86 injury accidents per year, and the group estimate for
this type of intersection, as obtained in Level II analysis, is about 4.99 injury accidents per year. Using Equations 1 through 3, one would obtain an estimate of 5.74, which is a linear combination of 4.99 and 5.86 injury accidents per year. For detailed calculation, see Lau and May (2, Sections VII.3 and VII.4). As far as the estimate of future safety of this intersection is concerned, it is believed that 5.74 is a better estimate than 4.99 because the group estimate of 4.99 cannot reflect the unique characteristics of this intersection. On the other hand, the accident history of 5.86 is not an optimal estimator because it is likely that the safety of this intersection would somehow revert to the mean value (4.99) in the future. Thus the Level III estimate is usually regarded as the best estimate for this purpose.

PDO Accidents From the earlier table, the Level III estimate for this intersection is 17.94. This value could be used as an estimate of the future safety (PDO accidents) of this intersection under such conditions.

Fatal Accidents Also from the table, the Level III estimate for this intersection is 0.141. By a similar token, the value 0.141 could be used as the estimate of future safety (fatal accidents) for this intersection.

Signal Timing Changes in Network Simulation Studies

Using similar reasoning, one could use the same method (the Level III estimate) to estimate the safety of intersections that are subject only to changes in minor signal timing intervals in network simulation and optimization studies. It is not implied that signal timing settings and phases are not important to the safety of intersections; it means only that the current prediction models could not be used for such purposes.

Before-and-After Studies

The aim of most before-and-after studies is to estimate the treatment effects of some improvement schemes. Because of the selection process and the "regression-to-mean" effect, however, one should look at the following comparison:

"COMPARING what the safety would have been 'after' had treatment not been applied WITH what safety was 'after' with treatment in place."

The intersections selected for the study are usually those with poor recent accident records; the time of implementing some measure can be as short as 6 months or so. The problem is quite clear in Figure 6 with the horizontal axis representing time in years and the vertical axis representing number of accidents per year. As a result of random fluctuation of accident occurrence, one might find curves like the solid line in Figure 6. For example, at time = 2 yr, let's say the intersection was detected as a black spot intersection and 6 months later an improvement measure is applied to it. The dotted line represents accident occurrences after an improvement measure with a treatment of 8 is applied to it at time = 2.5 yr. In a conventional before-and-after study, the measured treatment effect would have been 8' in Figure 6, as opposed to the real treatment effect of 8. To estimate the real treatment 8, one needs to find an estimate of m as shown in the same figure. It is suggested that Level III estimates would be a good candidate. On the other hand, the period between identification and implementation is in the range of 2 to 3 yr; then the problem would not be very serious at all because of the extra long buffer period allowed. This could easily be seen in Figure 6 as well. Specifically, one would like to know the meaning of the following three estimates, why they are different, and how they are related to before-and-after studies:

1. 4.99—Level II,
2. 5.86—accident history; and
3. 5.74—Level III.

The Level III estimate (= 5.74) represents the future safety measure of the intersection if the conditions of the intersection remain unchanged, and the "would have been" safety measure of the intersection in the "after" period if no treatment had been applied. One of the reasons that the accident history (5.86) is not the same as the Level III estimate is because of the random fluctuation of accident occurrences. It also is expected that the future safety measure of this intersection is likely to move closer to that of the expected group characteristics, which is 4.99 in this particular case. The argument for not using the accident history to estimate the future safety of this intersection, even though no changes are anticipated in the future, is because of the regression-to-mean effect found in many accident studies. Another element that could have caused the difference between 5.86 and 4.99 is the unique characteristics of the intersection that could not be captured by the model (Level II). As a compromise measure, a linear combination estimator, such as a Level III estimate, could be used. This is called m in Figure 6. Furthermore, the measure m' as shown in Figure 6 will not represent the safety of the intersection of the "after" period if an improvement measure is not applied. However, another measure of safety such as m (and not m') is exactly what is required for a meaningful before-and-after study because one would like to compare this measure with the after-period count. Furthermore, the difference or ratio of these two quantities represents the real improvement or the treatment effect. Finally, it can be said that the Level III estimate (= 5.74), and not 4.99 or 5.86, is the safety measure that should be used in any before-and-after study as the safety measure for the "after" period had treatment not been applied; then it should be compared with the safety measure with treatment in place. The interpretation for PDO and fatal accidents would be the same, and no numerical illustration is needed for these two models.

It is believed that a Level III prediction estimate should be used when applicable, and it could be quite different from the recent accident history of an intersection. A comparison of the observed values and Level III estimates in Figure 7 would reveal that they are very similar. This similarity is due mainly to the fact that the intersection was chosen at random for illustration purposes. If the intersections had been chosen on the basis of their recent poor accident records, however, as in most before-and-after studies, there could have been a big difference between them. Consequently, one would then appreciate the importance of Level III estimates in improvement studies to avoid an inflated treatment effect.
CONCLUSIONS

One can see that the three-level prediction procedure provides a very detailed, comprehensive, yet flexible framework for safety evaluations of highway segments. Meanwhile, it is also evident from the preceding discussion that great care should be taken in using those estimates for different purposes. It is apparent that, as accident prediction models are becoming more sophisticated and important in safety studies, a close link should be developed between people who are developing those models and those who are applying them in practice, so that maximum benefits can be obtained. Finally, it should be recognized that accident prediction models are only association relationships and do not represent cause-and-effect relationships. That fact might present some problems in improvement studies; however, the association relationships could be used for accident surveillance studies.

ACKNOWLEDGMENTS

The authors acknowledge with thanks the sponsorship of this research by the California Department of Transportation and the Federal Highway Administration. The permission of those agencies to publish this paper is also acknowledged. They wish to thank L. Seams of CALTRANS for reviewing this paper and for his suggestions during the course of research. The authors also thank Professors Scott and Breiman of the Statistics Department of the University of California, Berkeley, for their valuable suggestions and advice during the course of the study.

REFERENCES


The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the California Department of Transportation. This report does not constitute a standard, specification, or regulation.

Publication of this paper sponsored by Committee on Traffic Records and Accident Analysis.