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Evaluation of a Proposal to Set a Goal for the Virginia Strategic Highway Safety Plan of a Forty Percent Reduction in Traffic Fatalities and Injuries by 2010

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16. Abstract

The purpose of this study was to determine whether a 40% reduction in traffic fatalities and injuries by 2010 is a reasonable goal to include in Virginia's state-level strategic highway safety plan or whether such a goal is overly optimistic. To achieve the study objective, the scope of the study was limited to making the following determinations:

1. Forecast the total number of traffic fatalities and injuries in Virginia in 2010 assuming three scenarios: In Scenario 1, no state-level traffic safety plan or major traffic engineering safety improvements are implemented between now and 2010. In Scenario 2, only four traffic engineering improvements are made between now and 2010. In Scenario 3, a primary seat belt law along with the four engineering improvements from Scenario 2 are implemented.

2. Determine the probability that Virginia can achieve a 40% reduction in fatalities and injuries by 2010 under Scenarios 2 and 3.

3. Determine realistic goals for the reduction of traffic fatalities and injuries in Virginia in 2010.

Based on the forecasts under the three scenarios, the 40% reduction goals are overly optimistic. Assuming a normal distribution of the forecasts, the probabilities of achieving 40% reduction goals for fatalities and injuries are very low or low. Under Scenario 2, if the four engineering treatments are implemented at the 50% level, the probabilities that Virginia would achieve 40% reductions in 2010 are 1.2% for fatalities and 0.012% for injuries. Under Scenario 3, assuming that the primary enforcement seat belt law was enacted and the four engineering treatments were implemented at the 50% level, the probabilities are 8.6% for fatalities and 0.05% for injuries.

Accounting for a slight increase in fatalities and injuries in 2010 compared to 2004, realistic goals for Virginia are a 10% (maximum of 20%) reduction goal for fatalities and a 5% (maximum of 10%) reduction goal for injuries. These recommended goals assume that Virginia enacts a primary enforcement seat belt law and exercises enforcement efforts accordingly and deploys engineering crash countermeasures comparable to the 20% to 30% level of implementation of the four treatments used in this study, namely, (1) adding an exclusive left-turn lane to intersections, (2) modifying the signal change intervals, (3) installing centerline rumble strips, and (4) installing/upgrading guardrail.

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FINAL REPORT

EVALUATION OF A PROPOSAL TO SET A GOAL FOR THE VIRGINIA STRATEGIC HIGHWAY SAFETY PLAN OF A FORTY PERCENT REDUCTION IN TRAFFIC FATALITIES AND INJURIES BY 2010

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ABSTRACT

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INTRODUCTION

In 2005, the American Association of State Highway and Transportation Officials (AASHTO) published a strategic highway safety plan. Many states including Virginia have been creating their own state-level versions of a strategic highway safety plan using the AASHTO plan as a model. The goal of these state-level plans, as with the AASHTO plan, is to reduce the number of traffic fatalities and injuries. In Virginia, the Virginia Department of Transportation (VDOT) and the Department of Motor Vehicles (DMV) have been collaborating with other state agencies to create such a plan.

One of the principal tasks that must be undertaken as part of the creation of a strategic highway safety plan is setting goals for the reduction of traffic fatalities and injuries. During the course of a meeting in January concerning the state-level strategic highway safety plan for Virginia, the setting of goals for reductions in traffic fatalities and injuries was discussed. These goals should lie within a reasonable and achievable range, but they should be high enough to improve traffic safety in Virginia significantly. It was suggested by some of the people in attendance that reductions of 40% in both fatalities and injuries would be reasonable goals to set for the target year of 2010. Although the arguments offered in support of these goals were quite varied, one of the principal arguments was the fact that the United Kingdom had achieved approximately a 40% reduction in fatalities and serious injuries in 2000 as a result of its national traffic safety improvement plan, which was initiated in 1987.

PURPOSE AND SCOPE

The purpose of this study was to determine whether a 40% reduction in traffic fatalities and injuries by 2010 is a reasonable goal to include in Virginia's state-level strategic highway safety plan. To offer reasonable goals, all major safety improvement programs and policies included in the state-level plan and their likely effects on fatalities and injuries would need to be known. At the time this study was undertaken, they were unknown. However, with certain assumptions, it would be possible to calculate the probability that Virginia could accomplish a 40% reduction in fatalities and injuries by 2010 based on *forecasts* of fatalities and injuries. Thus, as a temporary measure, this study took into account a primary enforcement seat belt law that might be included in the final action plan and four engineering countermeasures: (1) adding

an exclusive left-turn lane to intersections, (2) modifying the signal change intervals, (3) installing centerline rumble strips, and (4) installing/upgrading guardrail.

The scope of this study was limited to making the following determinations, which should be sufficient to make the further determination whether the goal to reduce fatalities and injuries by 40% by 2010 is reasonable:

1. Forecast the total number of traffic fatalities and injuries in Virginia in 2010 assuming three scenarios: In Scenario 1, no state-level traffic safety plan or major traffic engineering safety improvements are implemented between now and 2010. In Scenario 2, only four traffic engineering improvements are made between now and 2010. In Scenario 3, a primary seat belt law along with the four engineering improvements form Scenario 2 are implemented.

2. Determine the probability that Virginia can achieve a 40% reduction in fatalities and injuries by 2010 under Scenarios 2 and 3.

3. Determine realistic goals for the reduction of traffic fatalities and injuries in Virginia in 2010.

METHODS

Data Collection

Historical annual traffic crash data in Virginia for the years 1951 through 2004 were compiled from *Virginia Traffic Crash Facts* (Virginia Department of State Police, 1952-1985; Virginia Department of Motor Vehicles, 1986-2005). (Data from 2005 had not been released at the time of this study.) Traffic crash data include the number of injuries and fatalities for each year. Vehicle miles traveled (VMT), which is one of the most popular traffic crash exposure metrics, was also compiled for use as a possible reference.

Scenario Setting

Three Scenarios

To provide forecasts of traffic fatalities and injuries for Virginia between 2006 and 2010, the crash countermeasures and safety policies (as well as their effects on safety) of the strategic safety plan to be implemented during this period would have to be known. Since the plan was still being formulated in April 2006, its specifics were unknown at the time of this study. Therefore, three provisional scenarios were considered as a way to forecast fatalities and injuries. Scenario 1 assumes that no major traffic safety plan or engineering treatments will be implemented between now and 2010. Scenario 2 assumes that only engineering interventions for improving traffic safety will be made between now and 2010. Scenario 3 assumes that legislative *and* engineering interventions for improving traffic safety will be made between now

and 2010. To select specific measures for legislative and engineering interventions and use their safety effects for forecasting, a literature review was performed.

Engineering Interventions

For Scenarios 2 and 3, engineering measures for safety improvement were considered. NCHRP Project 17-25 (Transportation Research Board [TRB], 2005) discussed traffic safety effects and corresponding predictive certainties of 100 potential traffic engineering treatments for improvements in safety. Many of the 21 treatments rated with a high or medium-high predictive certainty level are not easily implemented without further study (e.g., the removal of a traffic signal). However, some treatments are widely applicable, and four of these treatments were used in this study: (1) adding exclusive left-turn lanes at intersections to improve intersection safety, (2) modifying signal change intervals to improve pedestrian safety, (3) installing centerline rumble strips on rural two-lane roads to prevent roadway departure, and (4) installing or upgrading guardrails to prevent roadway departure.

These four treatments address three important elements among eight plan elements included in the draft of the strategic safety plan in Virginia: pedestrian and bicyclist safety, intersection safety, and roadway departure. Among the remaining five elements (driver behavior, special users, work zone safety, traffic records, and transportation safety planning), driver behavior will be addressed by a legislative measure.

Crash or accident reduction factors (CRFs or ARFs) and crash or accident modification factors (CMFs or AMFs) are useful for predicting the effects on traffic safety of the engineering treatments. A CRF is the percentage reduction in crashes expected from the implementation of a specific engineering treatment (e.g., installation of guardrail). An AMF is the percentage derived from a CRF with a relation of AMF = 1 – CRF. Thus, a CRF of 15% (meaning a 15% reduction in crashes) equals an AMF of 0.85, which means a reduction in crashes to 85% of an original level.

AMFs help states develop and implement the strategic highway safety plan (TRB, 2005) by offering likely reductions in crashes attributable to specific engineering treatments before the implementation of such treatments. AMFs are currently used in the *Interactive Highway Safety Design Model*, *SafetyAnalyst,* and *Highway Safety Manual* developed by the Federal Highway Administration (FHWA) (Krammes and Hayden, 2003; FHWA, 2006; TRB, 2006). The CRFs of the four treatments are presented in Table 1, converted from the AMFs in Table 3 in the 2005 TRB report.

Legislative Intervention

For Scenario 3, a legislative measure for safety improvement is considered in addition to the four engineering measures. Several legislative measures might be included in a strategic highway safety plan, such as stronger penalties for traffic violations, an open container law, and an increase in the minimum age for receiving a driver's license. However, their quantitative effects on safety are not well known; thus, they could not be used for this study with a reasonable level of confidence in their effectiveness.

However, studies of primary enforcement seat belt laws appear to agree on the safety effects of such laws. Many studies (e.g., Lui et al., 2006; Charles and Williams, 2005; Shults et al., 2004) concluded that adopting or converting to a primary enforcement seat belt law (in conjunction with comparable enforcement efforts) increases the seat belt usage rate, thereby resulting in declines in fatalities and/or injuries. Therefore, in lieu of any knowledge of the safety laws and programs that may be included in a state-level strategic highway safety plan for Virginia, this study considered only the safety effects of a primary enforcement seat belt law on the number of fatalities and injuries. It assumes that the law is enacted in 2006 and begins to be enforced by the end of 2006; thus crash reductions attributable to the law begin in 2007. A literature review identified many studies (e.g., Charles and Williams, 2005; Shults et al., 2004; Salzberg and Moffat, 2002; Houston and Richardson, 2002; Grabowski and Morrisey, 2002; Dinh-Zarr et al., 2001; Ulmer, Preusser, and Preusser, 1995) that investigated the effectiveness of primary seat belt laws, and these studies provided the safety effects of such a law.

Implementation Levels

Four implementation levels of the four engineering treatments were considered: two were optimistic and two were practical. The two optimistic levels were *High* and *Very High*. *High* assumes that 50% of the existing facilities receive the treatments; *Very High* assumes 90%. For example, adding exclusive left-turn lanes at *High* means that an exclusive left-turn lane is added to both approaches of 50% of all appropriate intersections in Virginia. Among the remaining 50% of intersections, some might already have left-turn lanes and some cannot physically house left-turn lanes.

Therefore, *High* is an optimistic and very aggressive engineering implementation in practice. In this regard, the 90% level might be practically unachievable because it is very unlikely that 90% of all intersections could have exclusive left-turn lanes added. Therefore, the 50% level is considered the level optimistically high enough to account for the safety effects attributable to other engineering countermeasures that are not considered for this study but might be implemented by the strategic safety plan. Most of the discussions in this study are based on the results using 50% implementation.

Two levels of effectiveness were employed for the primary enforcement seat belt law: the optimistic level and practical level. Reductions of 13% in fatalities reported in Washington (Salzberg and Moffat, 2002) and 4% in injuries reported in California (Houston and Richardson, 2002) were used as the optimistic level, and reductions of 8% in fatalities reported as a median effect (Shults et al., 2004) and 4% in injuries in California were used as the practical level.

Baseline Model Development

To provide baseline projections of fatalities and injuries under status-quo conditions, univariate time-series analysis was used partly because historical traffic accident data were available and partly because the main purpose of the study was forecasting. Three types of time-series models were used:

1. *A linear trend model with autoregressive errors, denoted as Trend-AR model.* A linear trend model is a linear regression model with time and/or time variants (e.g., squared time) as an explanatory variable. Such models assume that patterns in observations are captured by a long-term trend curve. This model has been popular because it is straightforward to use and to interpret. Although the form of the model is very simple, it can fit data very well (Broughton, 1991; Oppe, 1989). In the presence of autocorrelation, an autoregressive model is incorporated into the linear trend model, which is denoted as a Trend-AR model for this study.

2. *An autoregressive distributed lag (ARDL) model with autoregressive (AR) errors (ARDL-AR) model.* An ARDL model assumes that past values of explanatory variables and/or a dependent variable affects the current value of the dependent variable in an autoregressive fashion. Intuitively, the model accounts for inertia often found in social phenomena, and the inertial effects are explained by integrated autoregressive lags (Yaffee and McGee, 2000).

   An AR error model was incorporated to account for potential remaining autocorrelation in errors after all lagged variables rid serial correlation in data. For this study, an ARDL-AR model included a lagged dependent variable in lag 1 and no other explanatory variable. This model is also viewed as an AR error model with a lagged dependent variable. This type of model is used to deal simultaneously with autocorrelation of the process and the error (Raeside, 2004). (Specifications and details on ARDL models are presented in Appendix A.)

3. *An autoregressive integrated moving average (ARIMA) model.* An ARIMA model is the most popular time-series model. It uses past values and past errors to uncover patterns and predict future values. The model was first introduced in the 1960s, and Box and Jenkins in 1976 provided a systemized approach to the model. Since then, the model has often been referred to as a Box-Jenkins model. (Specifications and details on ARIMA models are presented in Appendix A.)

The models do not explicitly account for factors affecting traffic safety; rather, they are based on the assumption that the combination of all effects on traffic safety reveals a pattern (or patterns) in traffic fatalities, which can be viewed as a basis of a typical univariate time-series approach.

Model Evaluation

Five measures indicating relative goodness-of-fit of the models were used: (1) mean square error (MSE), (2) mean absolute percent prediction error (MAPE), (3) Akaike's information criterion (AIC), (4) Schwarz Bayesian information criterion (SBC or BIC), and (5) coefficient of determination (R^2).

In case the best model could not be determined by these five fit measures, Armstrong's (1984) recommendation was adopted. Armstrong examined 40 forecasting studies and found that the use of sophisticated extrapolation methods did not significantly improve forecasting

accuracy. Based on his investigation, he suggested that researchers use simple methods and combine forecasts. He recommended averaging forecasts generated by three or four methods. Following Armstrong's recommendation, an averaging method for integrating forecasts was used to obtain the final forecasts of fatalities.

Although Armstrong recommended averaging forecasts by different models, he did not make any recommendation about forecast limits; no recommendations regarding combining forecast limits were found in other relevant literature. Averaging two limits is not desirable because it will make much less use of the narrow limits that are statistically highly confident (i.e., 95%). Therefore, the confidence limits from the two models were used without averaging them. Limits with wider widths were defined as wide limits, and limits with narrower widths were defined as narrow limits. This study kept both wide and narrow limits, and it used the narrow limits to calculate the probabilities of achieving reduction goals and the wide limits as extreme limits.

Forecasts

The inclusion of a lagged dependent variable into an ARDL-AR model renders the model unable to make direct predictions for future time periods (i.e., out-of-sample predictions). To obtain forecasts and their statistical confidence limits, simulation techniques needed to be adopted for such model. For an ARIMA model, direct forecasts were made through an ARIMA forecasting procedure.

Using 54 years of annual crash data, the number of traffic fatalities and injuries in Virginia was forecast for the years up to and including 2010. VMT was also forecast, and the results are provided in Appendix B as a reference.

RESULTS AND DISCUSSION

Historical Trends

The number of fatalities and injuries during the past 54 years is displayed in Figures 1 and 2. Figure 1 shows that the number of fatalities has fluctuated greatly and appears to have stabilized in recent years. However, this recent stability does not necessarily mean that traffic safety in Virginia is approaching a steady state. This stability in the numbers might be due to increased consistency in the police crash reporting system and may not continue due to natural fluctuation over time. A similar stabilized pattern can be found from 1985 through 1990, although there was greater variation then than in recent years. The compounding effect of all factors affecting traffic safety (e.g., demographic changes, economic conditions, improvement of vehicles and roadways, and policy changes) has also varied over time, and this also contributes to variations in the annual counts.

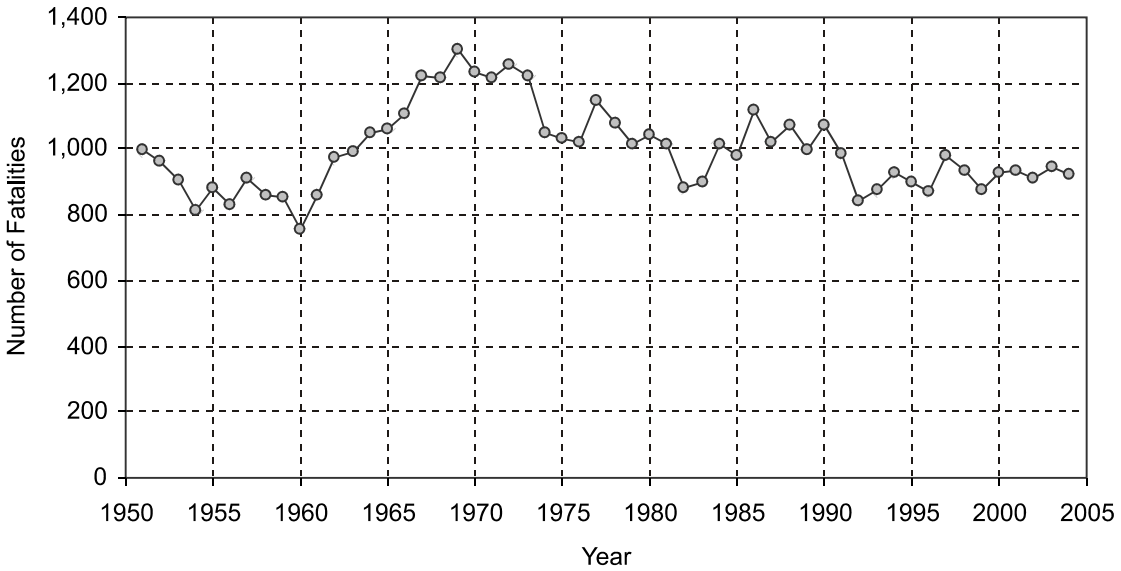


Figure 1. Traffic Fatalities in Virginia, 1951-2004

The number of injuries has steadily grown over time and seems to have reached a plateau during the past 10 years (see Figure 2). This upward trend is thought to be due to increases in the number of vehicles and VMT. This is confirmed by positive correlations of vehicle numbers and vehicle mileage with injuries using AR models (see Appendix C).

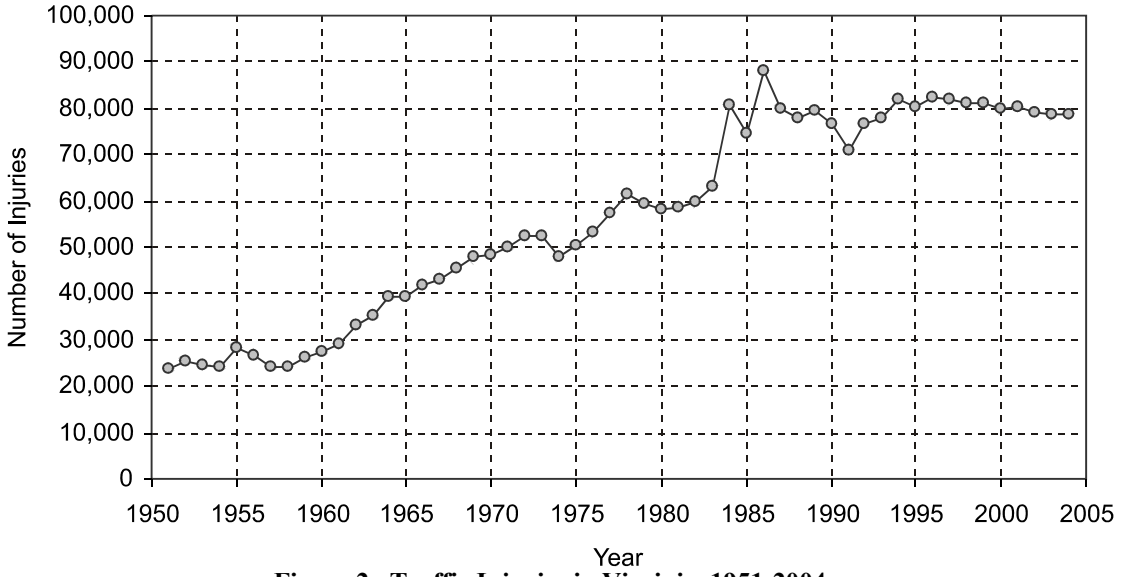


Figure 2. Traffic Injuries in Virginia, 1951-2004

Scenario 1: Trend-Based Outcomes (Passive)

The forecasts for this scenario were made under the assumption that Virginia would not implement any new traffic safety policy (e.g., primary enforcement seat belt law) or major engineering treatments for improving safety. Therefore, these forecasts can be viewed as a baseline projection of traffic accident figures for the state.

Fatalities

Linear trend models turned out to be of no help for the study because none of the time variables (i.e., time, time^2, and time^3) in the models was statistically significant after correcting for autocorrelation in errors. Therefore, the linear trend model was not used for forecasting fatalities. It should be noted that *linear* means linear in parameters, not linear in variables (for example, $y = \alpha + \beta \cdot x + \gamma \cdot x^2$ is linear in parameters, β and γ).

The ARDL-AR model and the ARIMA model were successfully estimated and produced two sets of forecasts. The forecasts using the ARDL-AR model were constructed through a simulation process, and their confidence limits were created by the Monte Carlo simulation technique. Forecasts and confidence limits of the ARIMA model were constructed directly from an ARIMA forecasting process.

For the ARDL(g,r)-AR(p) model with g dependant lags, r independent lags, and p AR lags in errors, adding a lagged dependent (g = 1) removed autocorrelation from the fatality series and led to the ARDL model with a *zero* order AR error (p = 0). No independent variable (r = 0) was included. Therefore, the final model is denoted as the ARDL(1,0)-AR(0) model (or just ARDL(1,0)), and the estimated model is written as follows:

$$fatality_t = 162.93 + 0.8351 \cdot fatality_{t-1} + e_t \text{, ARDL(1,0) model} \qquad \text{(Eq. 1)}$$

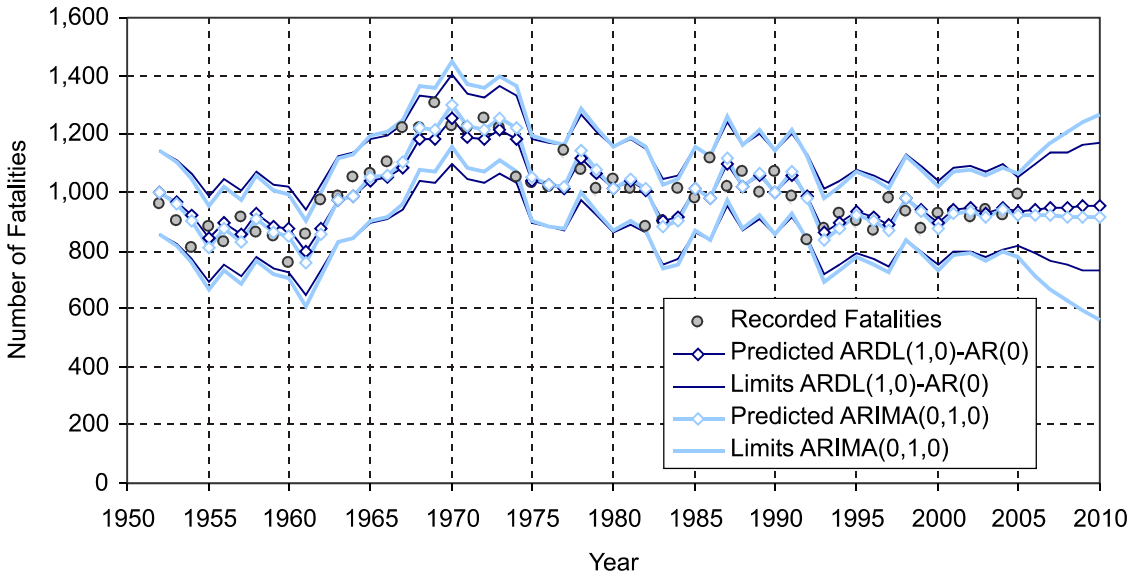
For the ARIMA (p,d,q) model with p AR order, d differencing level, and q moving-average (MA) order, the series did not seem to contain autocorrelation ($p = q = 0$) after transforming the data into a stationary fatality series by first differencing, $fatality_t - fatality_{t-1}$, ($d$ = 1). Therefore, the final ARIMA model specification is ARIMA(0,1,0), and the estimated model is as follows:

$$(fatality_t - fatality_{t-1}) = -1.4528 + e_t \text{, ARIMA(0,1,0) model} \qquad \text{(Eq. 2)}$$

Interestingly, these final model specifications, ARDL(1,0)-AR(0) and ARIMA(0,1,0), mean that the series of fatalities does not require time-series modeling components. Specifically, AR and/or MA components are not needed here, after appropriate data transformation, which included adding a lagged dependent variable for the ARDL-AR model and first differencing for the ARIMA model. Details about estimation results of these models are presented in Appendix D.

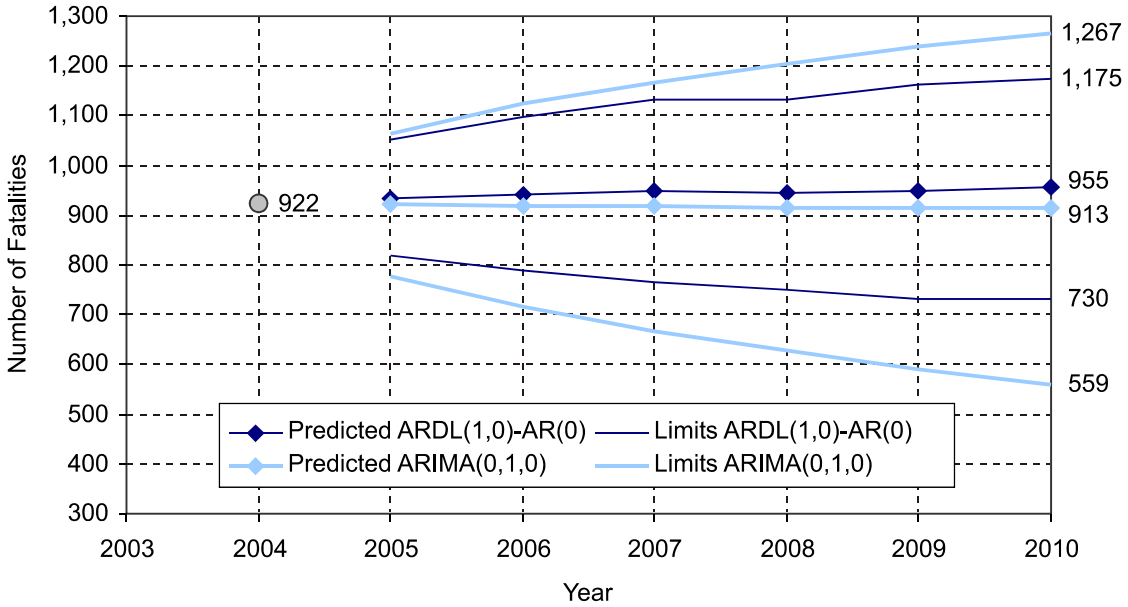
Figures 3 and 4 display two forecasts overlaid on recorded fatalities. (Separate graphs from each model are provided in Appendix E.) As is apparent in Figure 3, the two forecasts are very similar, and their confidence limits are quite similar for the sample data period.

However, the forecasts and confidence limits of each model seem to be different for 2005 through 2010. Figure 4 shows that traffic fatalities in 2010 are forecast to be 955 by the ARDL(1,0)-AR(0) model and 913 by the ARIMA(0,1,0) model. The ARDL(1,0)-AR(0) model forecast an increase from 922 fatalities in 2004, whereas the ARIMA(0,1,0) model forecast a decrease.



Note: All prediction limits are constructed at the 95% confidence level.

Figure 3. Forecasts of Fatalities in Virginia, Entire Period



Note: All prediction limits are constructed at the 95% confidence level.

Figure 4. Forecasts of Fatalities in Virginia, 2005-2010

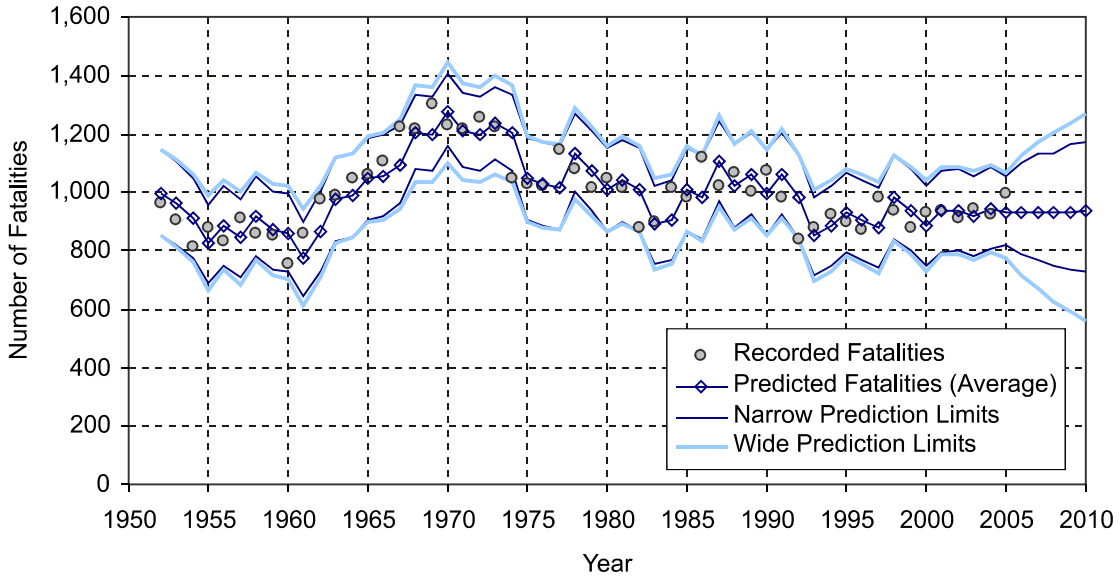
The two models have noticeably different confidence limits for future years, as shown in Figure 4. The limits of the ARIMA(0,1,0) model diverge much more rapidly than the limits of the ARDL(1,0)-AR(0) model. For 2010, the former are about 60% wider than the latter (708 versus 455 in terms of width of the limits). The reason for narrower limits of the ARDL(1,0)-AR(0) model is the inclusion of a lagged dependent variable as an explanatory variable.

Models can be compared using five statistical measures of relative goodness-of-fit, including MSE, MAPE, AIC, SBC, and R^2 values. (These measures and estimation results of

each model are presented in Appendix D.) According to the five goodness-of-fit measures, the ARDL(1,0)-AR(0) is slightly better than the ARIMA(0,1,0) model. However, the differences are not big enough to favor decisively one model over the other; thus, the researcher investigated ways to incorporate both results in the final forecasts and confidence limits.

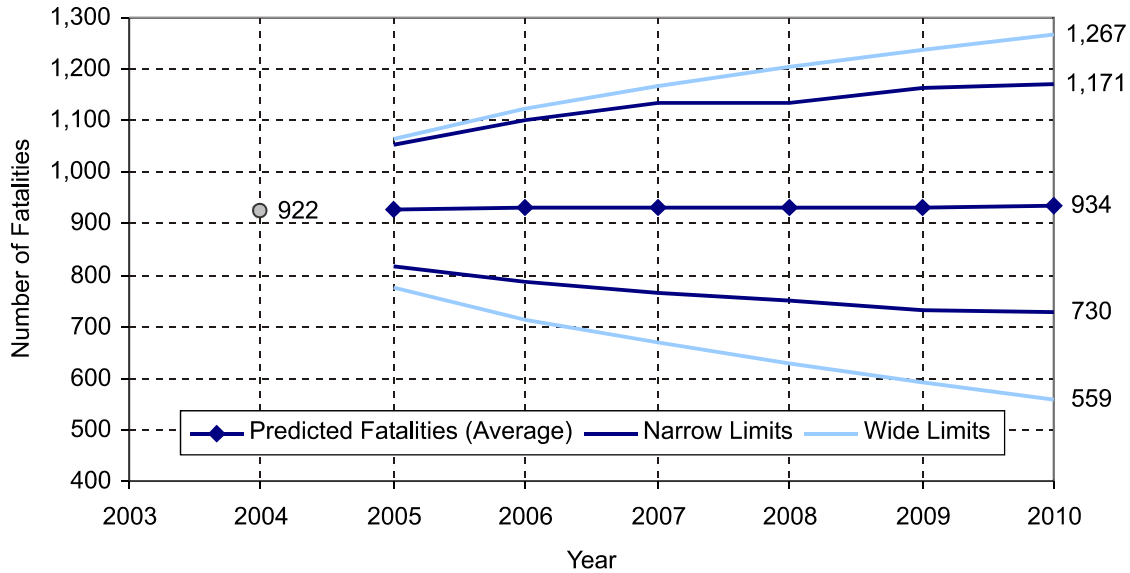
Because the model comparison using the five fit measures produced an indecisive conclusion, forecasts from different models were averaged (which was the recommendation of Armstrong [1984]). The two forecasts are quite similar, although their limits are not. The confidence limits from the two models were used (without averaging them) as wide and narrow limits. For the period 2005 through 2010, the ARIMA(0,1,0) limits became the wide limits and the ARDL(1,0)-AR(0) limits became the narrow limits. The wide limits can be regarded as extreme confidence intervals. It should be noted that both limits were obtained at the same 95% confidence level. The final fatality forecasts and two confidence limits are presented in Figures 5 and 6.

Assuming that there is no implementation of a state-level strategic highway safety plan and/or any major engineering safety improvement, the best forecast of fatalities in Virginia for the year 2010 is 934 deaths. The conservative confidence limits of the forecast are 730 and 1,171, and the broad forecast limits are 559 and 1,267 at the same 95% confidence level.



Note: All prediction limits are constructed at the 95% confidence level.

Figure 5. Final Fatality Forecasts for Virginia, Entire Period



Note: All prediction limits are constructed at the 95% confidence level.

Figure 6. Final Fatality Forecasts for Virginia, 2005-2010

Injuries

The linear trend model, the ARDL-AR model, and the ARIMA model were used to estimate injuries. Three series of forecasts with their corresponding confidence limits were produced through a forecasting process or through simulation. The linear trend model employed an AR model for errors because model residuals suffered autocorrelation. AR(1,2,4) was recommended through a stepwise autoregressive regression process. The final trend model with the AR(1,2,4) error model, which is designated as Trend-AR(1,2,4), is expressed as follows (along with estimated parameters):

$$injury_t = 23{,}698 + 77.40 \cdot time^2 - 1.09 \cdot time^3 + v_t \text{, trend model, and}$$
$$v_t = 0.353 \cdot v_{t-1} + 0.307 \cdot v_{t-1} - 0.380 \cdot v_{t-1} + e_t \text{, AR(1,2,4) model} \qquad \text{(Eq. 3)}$$

Although the AR(1,2,4) terms were statistically suggested, they might have resulted from disturbed residuals generated by overfitting the series.

The lagged dependent variable in the ARDL model could not handle all serial correlations embedded in the injury series, which was indicated by autocorrelation in residuals. To account for the remaining serial correlation in errors, an AR model was successfully applied. The final model specification is ARDL(1,0)-AR(1) and is written as follows, with parameter estimates:

$$injury_t = 2294 + 0.978 \cdot injury_{t-1} + v_t \text{, ARDL(1,0) model, and}$$
$$v_t = 0.279 \cdot v_{t-1} + e_t \text{, AR(1) model} \qquad \text{(Eq. 4)}$$

After stabilizing the injury series using first differencing in the ARIMA model, the MA component with only lag 2 fit the differenced series well. This is called a *subset model*. (An ARIMA model with AR and/or MA parameters for only some lags is called a *subset* or *additive model*.)

Thus, the final model is ARIMA(0,1,(2)) and is written as:

$(injury_t - injury_{t-1}) = 982 + e_t + 0.407e_{t-2}$: ARIMA(0,1,(2)), which is also called IMA(1,(2)) (Eq. 5)

Unlike fatality models containing no time-series components for errors, all three injury models include either AR or MA components for errors. The estimation results and the goodness-of-fit of these injury models are shown in Appendix D.

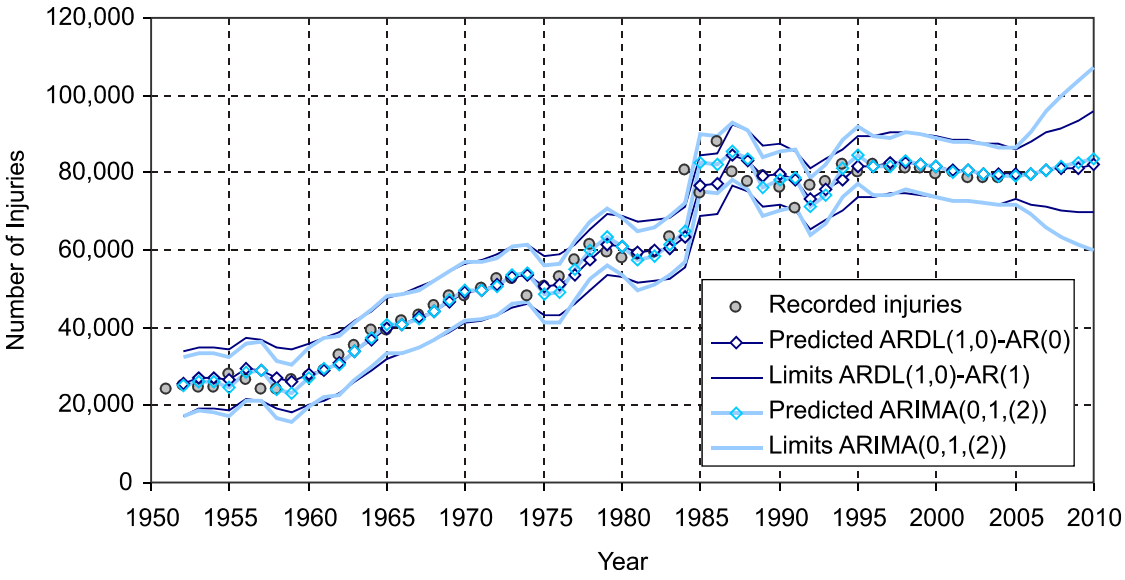
A comparison of the models was performed using five goodness-of-fit measures. Regarding model performance, ARDL(1,0)-AR(1) cannot be differentiated from ARIMA(0,1,(2)) in that the values of goodness-of-fit measures are quite close. However, the ARIMA model forecast slightly more injuries for 2010 than did the ARDL-AR model.

The Trend-AR model produced a considerably different forecast from the other two models. The Trend-AR(1,2,4) model produced downward forecasts for 2005 through 2010, whereas the other models forecast slight increases. In 2010, the Trend-AR model forecast 15% fewer injuries than what was recorded in 2004. A 15% reduction in injuries by 2010 without any changes in the current efforts to improve safety seems unlikely without any immediate and significant changes in people's driving behavior and in their attitude toward safety.

Since a trend model reflects the overall shape of the series over time, the recent trend (level and slightly downward) in injuries is likely to have excessive influence on the model specification, which consequently leads to forecasts with large reductions in injuries (for example, the 15% reduction for 2010). Although the trend of increasing numbers of injuries seems to stall in recent years, such trends should still be understood to be under temporal fluctuation. The Trend-AR model is influenced by its specification rather appreciably, reflecting the recent trend (see Eq. 3).

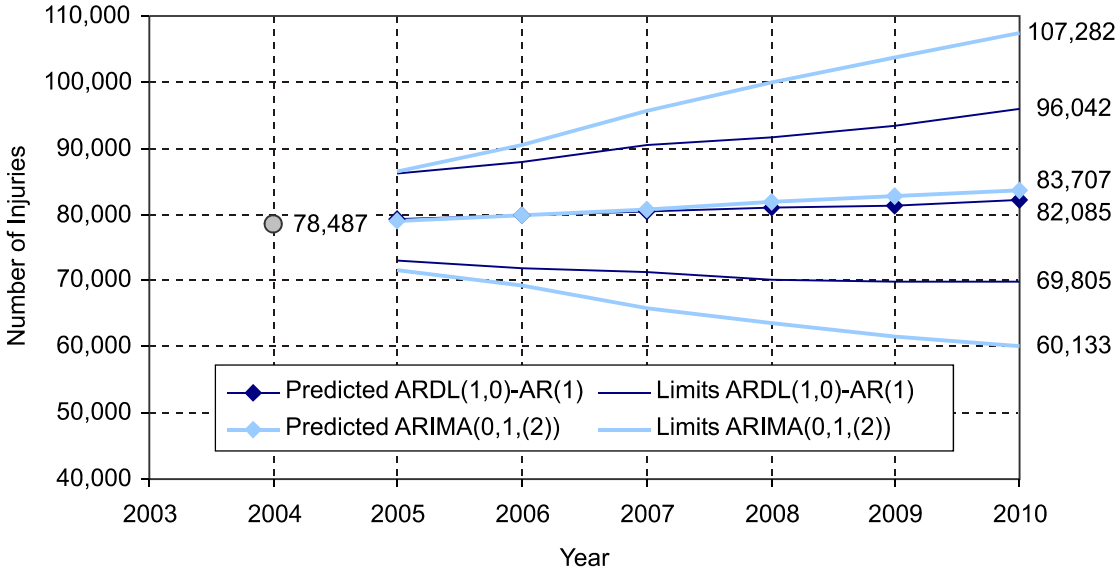
According to five goodness-of-fit measures, the best model selection was indecisive in that MSE, MAPE, and R^2 values favored the Trend-AR model and the AIC and SBC values favored the ARDL-AR and ARIMA models. Considering the intuitive and statistical statements associated with the Trend-AR model (i.e., an unreasonably large decrease in injury forecast without any safety improvement effects and indecisive model selection by fit measures), the Trend-AR model was regarded to be unacceptable for injury forecasting; thus, it was not used to forecast injuries.

Figures 7 and 8 show forecasts and confidence limits generated from the ARDL-AR and ARIMA models. (Separate graphs for all three models, including Trend-AR, are provided in Appendix E.) The number of injuries forecast by the ARDL(1,0)-AR(1) and ARIMA(0,1,(2)) models were not very different for the entire period, and for the data period, the widths of



Note: All prediction limits are constructed at the 95% confidence level.

Figure 7. Forecast of Injuries in Virginia, Entire Period



Note: All prediction limits are constructed at the 95% confidence level.

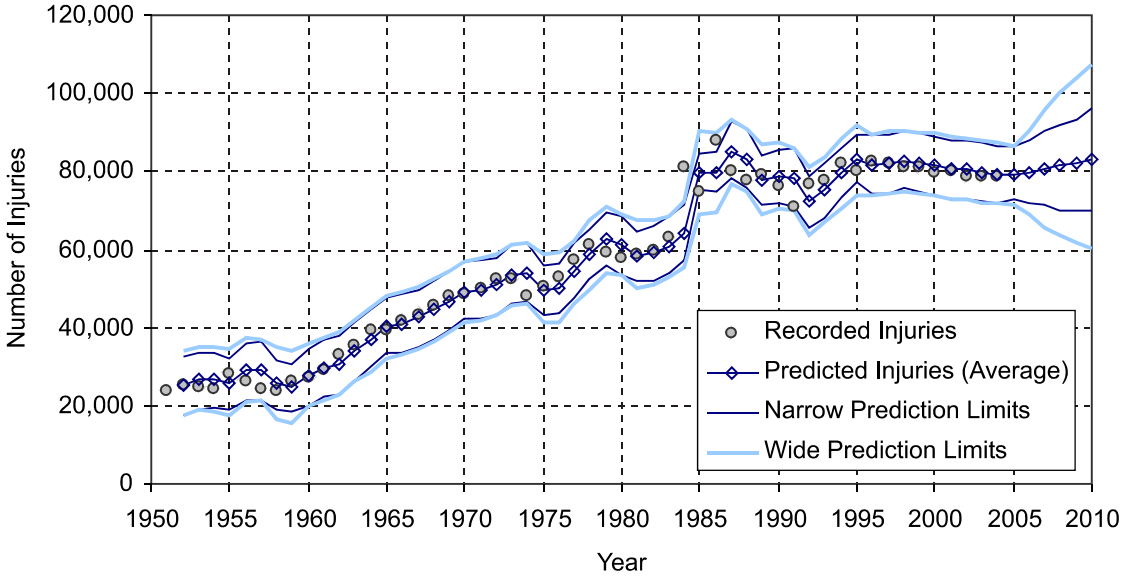
Figure 8. Forecast of Injuries in Virginia, 2005-2010

prediction limits were practically identical in that the average difference in widths was about 1%. However, forecasts of the ARDL(1,0)-AR(1) model appear to be less responsive to abrupt changes in injuries than forecasts of the ARIMA(0,1,(2)) model.

An apparent difference between forecast results was found in the prediction of confidence limits for 2005 through 2010. For 2010, the ARIMA model forecast 4% fewer injuries in 2010 than did the ARDL-AR model, but the ARIMA prediction limits were about 60% wider than the ARDL-AR limits. The narrower prediction limits and reduced responsiveness to sudden changes

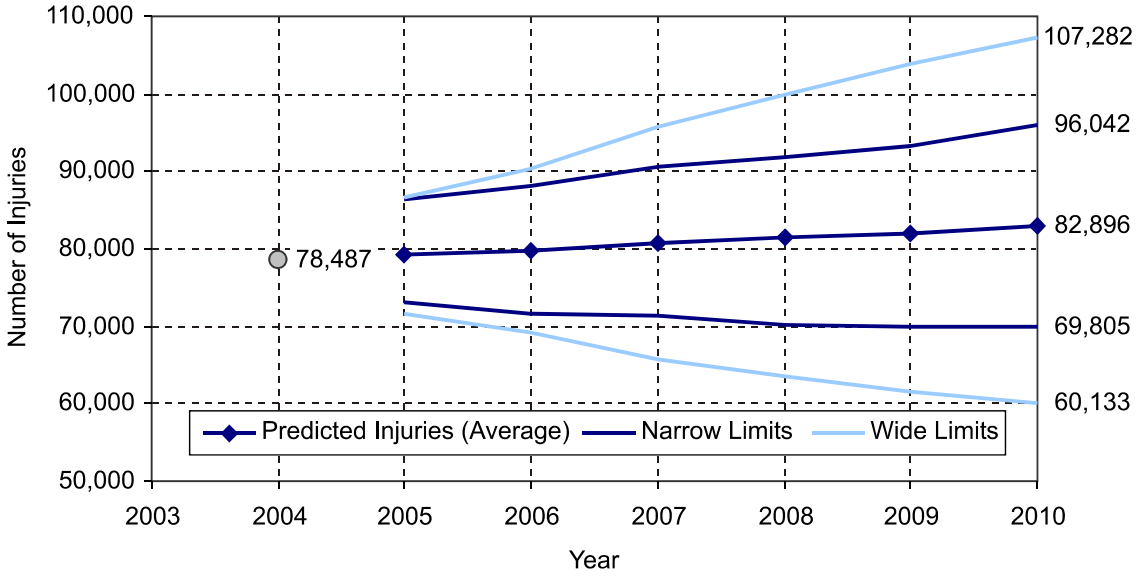
in the series of the ARDL-AR model are due to the presence of a lagged dependent variable as an explanatory variable.

For final injury forecasts, averaging forecast values was again employed. As in the case of fatalities, two prediction limits were used as narrow and wide limits of the averaged injury forecasts. It should be remembered that all limits were obtained at the same 95% confidence level although they were fairly different for the period 2005 through 2010. The final forecasts and confidence limits for injuries are presented in Figures 9 and 10.



Note: All prediction limits are constructed at the 95% confidence level.

Figure 9. Final Injury Forecasts for Virginia, Entire Period



Note: All prediction limits are constructed at the 95% confidence level.

Figure 10. Final Injury Forecasts for Virginia, 2005-2010

It is worth mentioning that the models used for injury forecasts do not explicitly account for specific factors influencing traffic safety. Instead, the models assume that the combined effect of all the potentially influential safety-related factors reveals patterns over time. The temporal patterns in univariate time-series data are expected to be uncovered by the time-series models, which can be said to be a conceptual foundation of univariate time-series analysis.

If a state-level strategic highway safety plan and/or engineering-based accident countermeasures are not implemented, the best forecast of traffic injuries for Virginia for 2010 is 82,896. The conservative confidence limits of the forecast are between 69,805 and 96,042 and the broad forecast limits are 60,133 and 107,282 with the same 95% confidence level.

Forecasts Based on 1970-2004 Data

There are concerns about including very old data such as the data from 1950 for the model estimation. The crash reporting system, vehicle fleets, safety features, emergency medical service (EMS) system, and roadway system have changed dramatically since 1950. This raises questions about the consistency and quality of the crash data. In particular, the fatality trend presented in Figure 1 shows an obvious change around 1970. This change might have an impact on parameter estimation and thus affect future forecasts.

One way to address this concern is to re-estimate the models using only the data from the recent period and compare the resulting forecasts with those produced based on the data from the entire period. For this comparison, the data from 1970 through 2004 were treated as recent data and the fatality and injury models were re-estimated based on these recent data.

Using the recent data, an ARIMA model was estimated for injuries and fatalities separately. However, an ARDL-AR model failed to be estimated successfully for injuries and fatalities mainly because of the existence of remaining autocorrelations in the residuals of the model after all possible treatments were applied to correct the autocorrelation. However, a Trend-AR model was successfully estimated. Thus, the final 2010 forecast based on the recent data was an average of the two forecasts by the ARIMA and Trend-AR models, and narrower and wider intervals were obtained around the averaged forecast.

A total of 966 deaths was forecast, with a narrower interval of 746 through 1,186, and a total of 79,353 injuries were forecast, with a narrower interval of 65,323 through 93,383. In comparison with the results from the entire data set, 32 more deaths (3%) and 3,543 fewer injuries (4%) were forecast. Thus, it seems that the use of only the recent data did not appreciably affect the forecasts. This implies that use of the recent data was not different from use of the entire data in terms of the forecasts.

For forecasting limits, the narrower confidence interval of the models estimated from the recent data was compared to that estimated from the entire data. The width for fatalities was 3% smaller with the recent data than with the entire data. The width for injuries was 14% larger with the recent data than with the entire data. The smaller width of the forecast interval is better and is helpful for forecasting purposes. For fatalities, a 3% smaller width is equivalent to 6 fatalities.

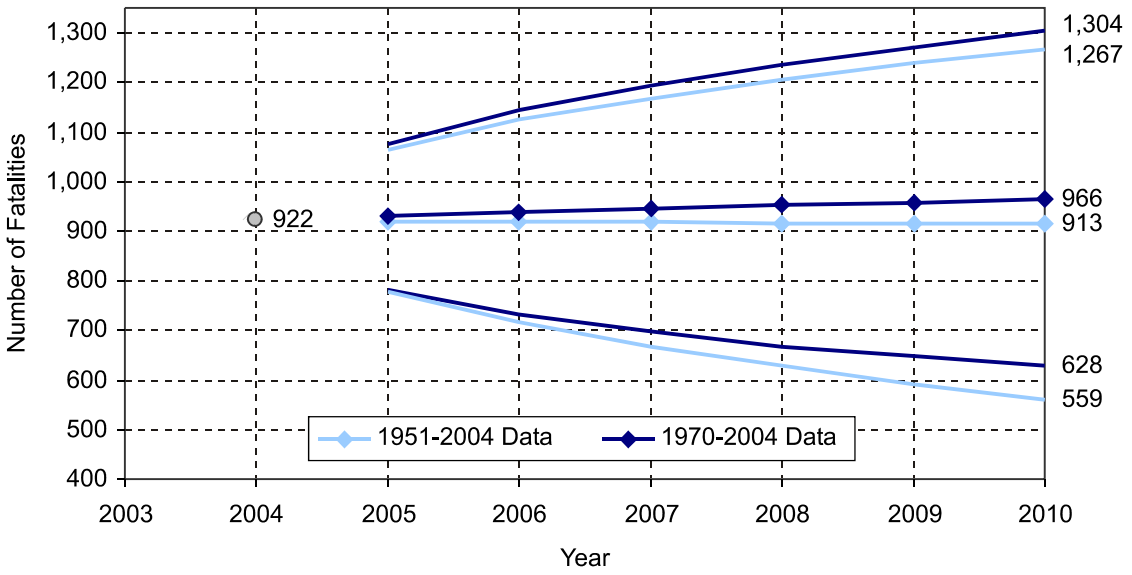
For injuries, a 14% smaller width is large enough to suggest that the forecast limits based on the entire data are better than those based on the recent data.

However, it is inappropriate to draw a conclusion with regard to model comparisons by comparing forecast results because the models used to produce the results are different. Specifically, the ARIMA and Trend-AR models became the final two models using the recent data, and their results were used to produce the forecast and confidence limits, whereas the ARIMA and ARDL-AD models were the final models using the entire data.

A direct comparison can be made only with the results of the ARIMA models because only an ARIMA model led to a successful convergence in the model estimation for both cases (i.e., the recent data [1970-2004] and the entire data [1951-2004]). The ARIMA results using the two datasets were provided in Figure 11 for fatalities and in Figure 12 for injuries. For fatalities, the forecast based on the recent data was higher than that based on the entire data by about 6%. The width of the confidence limits based on the recent data was narrower by 3% than that based on the entire data.

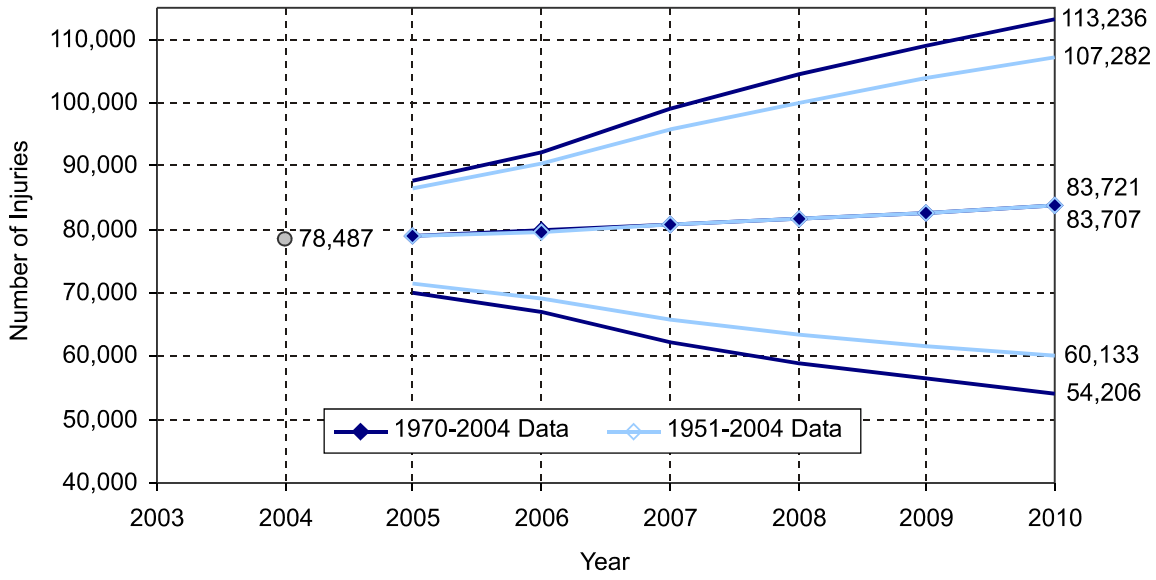
Although R^2 values of the two forecasting results cannot be compared because different subsets of the same data were used, the R^2 values for both models based on the same data period (1970-2004) were computed. According to the R^2 values, the models with the recent data were slightly better than the models with the entire data by 1.3% for fatalities and 0.2% for injuries, yet the differences were negligible. Thus, the models using the recent data did not perform much better than those using the entire data in terms of the R^2 values when the values were computed only for the recent data period.

According to these findings, the two forecasts and their limits were close enough to allow the conclusion that use of the recent data did not contribute to reducing the widths of forecast intervals and model performance in R^2, although the R^2 values cannot be used to make a



Note: All prediction limits are constructed at the 95% confidence level.

Figure 11. ARIMA Fatality Forecasts Using 1970-2004 Data



Note: All prediction limits are constructed at the 95% confidence level.

Figure 12. ARIMA Injury Forecasts Using 1970-2004 Data

statistically legitimate comparison of the two models. Moreover, for developing an ARIMA model, 50 observations are recommended as a minimum, and the recent data had only 35 observations. Therefore, the entire data period was chosen for use in this study.

Summary

Assuming that there is no implementation of a state-level strategic highway safety plan or any major engineering countermeasures, the best forecasts of fatalities and injuries in Virginia are 934 fatalities and 82,896 injuries in 2010. It is very probable that the number of fatalities will be between 730 and 1,171 for 2010 and that the number of injuries will be between 69,805 and 96,042 (at a 95% confidence level). Averaged fatality and injury forecast values and narrower forecast limits were used for Scenarios 2 and 3.

For providing better forecast limits, the narrower widths of confidence intervals between the two sets of intervals were adopted for Scenarios 2 and 3. Therefore, for fatalities, the widths of the ARDL(1,0)-AR(0) confidence intervals were applied to the averaged forecasts from Scenario 1 to obtain the final forecast limits. For injuries, the widths of the ARDL(1,0)-AR(1) confidence intervals were applied.

Using the data from the years 1970 through 2004 exclusively was not recommended for this study as a result of comparisons between two sets of forecasts, one based on the entire data (1951-2004) and the other based on the recent data (1970-2004). Therefore, the forecast results derived from the entire data were used as a basis for Scenarios 2 and 3.

Scenario 2: Engineering Interventions (Active)

Engineering Interventions and Their Effects

Engineering interventions for safety improvement were considered for Scenario 2. Among many specific traffic engineering treatments listed in NCHRP Project 17-25 (TRB, 2005), four treatments were employed as engineering interventions: (1) adding an exclusive left-turn lane at an intersection, (2) modifying signal change intervals, (3) installing centerline rumble strips on rural two-lane roads, and (4) installing or upgrading guardrails. The CRFs for the four treatments are provided in Table 1 and were used to predict reductions in fatalities and injuries attributable to the treatments.

Table 1. Crash Reduction Factors (CRFs) of Four Engineering Treatments

Treatment	CRF	Accident Type	Facility Type	Level of Predictive Certainty
Add an exclusive left-turn lane into all approaches	0.58	Fatal and injury crashes	4-leg rural stop-controlled intersections	High
	0.50		4-leg urban stop-controlled intersections	
	0.17		4-leg urban signalized intersections	
Modify signal change intervals	0.12	Injury crashes	4-leg signal intersections	Medium-High
Install centerline rumble strips	0.15	Injury crashes	Rural 2-lane roads	Medium-High
Install/upgrade guardrail	0.44	Fatal crashes	All roads	Medium-High
	0.47	Injury crashes		

Note: For details on facility type and level of predictive certainty, see Crash Reduction Factors for Traffic Engineering and Intelligent Transportation System (ITS) Improvements: State-of-Knowledge Report, *Research Results Digest 299,* Transportation Research Board, Washington, DC, November 2005.

CRFs were calculated from AMFs using the relationship of CRF = 1 - AMF, and they were interpreted as percentages of reductions in crashes. For example, the CRF of adding an exclusive left-turn lane on both approaches of a four-legged rural stop-controlled intersection is 0.58 for fatal and injury crashes. This means that fatal and injury intersection crashes are expected to be reduced by 58% at the intersections with four legs and stop controls when exclusive left-turn lanes are added on both approaches. The level of predictive certainty in Table 1 indicates how certain the suggested reduction percentages are from a statistical viewpoint; the results from studies using an empirical-Bayes method usually are rated high because of the high reliability of the method.

Assumptions for CRF Application

To apply the CRFs from previous studies, several assumptions had to be made:

1. If adding an exclusive left-turn lane, the CRFs are the same for fatal crashes and for injury crashes.

2. If adding an exclusive left-turn lane, the CRFs are the same regardless of the number of legs.

3. If modifying signal change intervals, the CRF is the same regardless of the number of legs.

4. Only undivided two-lane roads are considered for the installation of centerline rumble strips

5. If installing/upgrading guardrails, all roads including urban and rural roads are considered for the installation/upgrade.

6. All CRFs indicate reduced percentages of *crashes*, which it is assumed to correspond to equivalent reduced percentages of *victims* in the crashes.

7. Exact reductions indicated by CRFs are expected to occur without uncertainty after implementation of the treatments, implying 100% predictive certainty.

Under these assumptions, reduced fatalities and injuries were projected based on the final forecasts from Scenario 1. Forecasts with the implementation of the four engineering treatments were calculated by applying the CRFs in Table 1 to the final forecasts in Figure 10 from Scenario 1 (the steps of CRF application are explained shortly). The narrow limits from Scenario 1 were adopted and adjusted in response to the reduced forecasts.

Several steps taken to apply the CRFs to the forecasts under the four assumed implementation levels (i.e., 90%, 50%, 30%, and 20%) can be explained by using as an example the installation of centerline rumble strips:

1. Obtain the number of injury crashes that occurred on two-lane undivided rural roads in Virginia each year from 2000 through 2004: The SQL query in MS-ACCESS shown in Table 2 was used to retrieve the annual crash count from the VDOT Crash Report Database.

2. Compute the average number of injury crashes and the average number of total crashes over 5 years (2000-2004).

3. Compute the injury crash fraction by dividing the average number of injury crashes by the average number of total crashes.

4. Compute the injury crash countermeasure implementation fraction by multiplying the injury crash fraction from Step 3 by the implementation rate (e.g., 0.5 for 50% implementation).

5. Compute the injury crash reduction fraction by multiplying the injury crash countermeasure implementation fraction from Step 4 by the crash reduction factor (CRF) of installing centerline strips (i.e., CRF = 0.15).

6. Compute reduction in injuries due to the installation of centerline strips by multiplying the injury forecasts from Scenario 1 by the reduction fraction from Step 5.

Table 2. SQL Query to Retrieve Injury Crashes on Rural two-lane Undivided Roads in Virginia in 2000

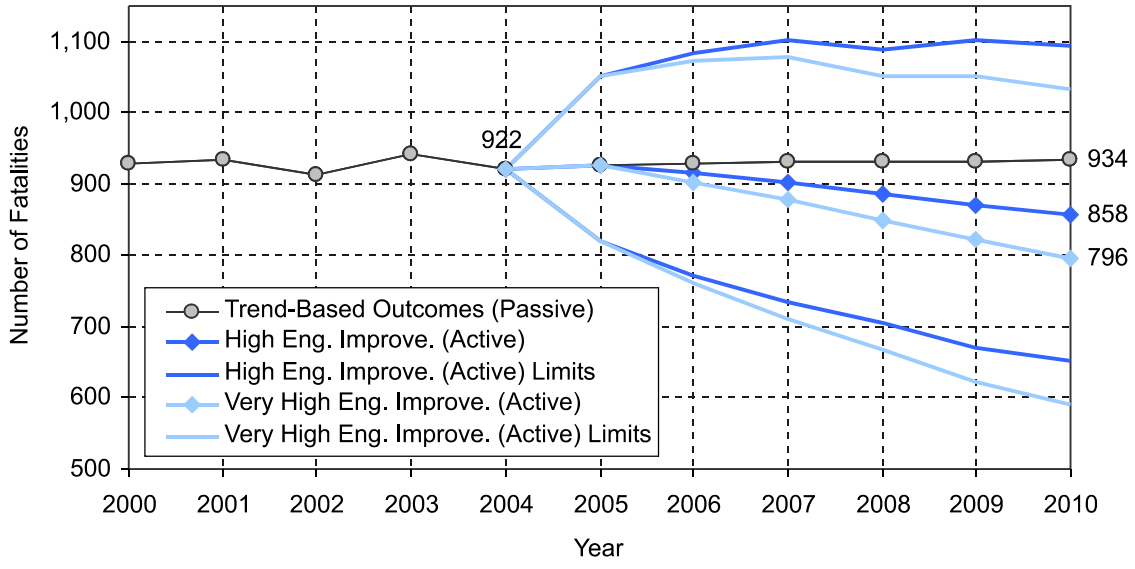
```
SELECT CRASHDOCUMENT.CRASHDATE, CRASHDOCUMENT.LANECOUNT,
CRASHDOCUMENT.FACILITY, CRASHDOCUMENT.SEVERITY, CRASHDOCUMENT.LOC
FROM CRASHDOCUMENT
WHERE (((CRASHDOCUMENT.CRASHDATE)>=#1/1/2000# AND
(CRASHDOCUMENT.CRASHDATE)<=#12/31/2000#) AND ((CRASHDOCUMENT.LANECOUNT)=2)
AND ((CRASHDOCUMENT.FACILITY)="0" Or (CRASHDOCUMENT.FACILITY)="B") AND
((CRASHDOCUMENT.SEVERITY)="2" Or (CRASHDOCUMENT.SEVERITY)="3") AND
((CRASHDOCUMENT.LOC)="0" Or (CRASHDOCUMENT.LOC)="1" Or
(CRASHDOCUMENT.LOC)="2" Or (CRASHDOCUMENT.LOC)="3" Or
(CRASHDOCUMENT.LOC)="4" Or (CRASHDOCUMENT.LOC)="7" Or
(CRASHDOCUMENT.LOC)="8"));
```

Two implementation levels (20% and 30%) were used to provide achievable reduction goals in fatalities and injuries. The forecast results based on these two levels of implementation are presented in Scenario 3.

Fatalities

Figure 13 shows forecast fatalities responding to the engineering treatments gradually implemented from 2006 through 2010 (i.e., 20% of the assumed implementation level is executed each year so that the assumed level is fully attained by the end of 2010). The passive trend-based outcome is the forecast from Scenario 1, which assumes no implementation of a strategic safety plan and/or major engineering treatments. A reduction in injuries attributable to the four treatments was applied to this forecast accordingly as described earlier in the six steps.

With 50% implementation, 858 fatalities are forecast as a result of traffic crashes in 2010. A 7% reduction from the 2004 level (and an 8% reduction from the 2010 trend-based outcomes)



Note: Forecast limits are constructed at the 95% confidence level and do not account for uncertainty in reductions due to the engineering treatments.

Figure 13. Reduced Fatality Forecast Attributable to Engineering Treatments

is expected to be achieved by implementing the four treatments at 50% implementation. However, the reduction percentage is very likely to be between –18.7% (i.e., 18.7% increase) and 29.2% at the 95% confidence level.

Thus, the reductions cannot be statistically detected and attributed to those treatments because the recorded fatalities in 2004 (922 deaths) fell within the forecast limits of the *High* as well as the *Very High* engineering improvements (90% implementation).

However, as time goes by, more accident data will be collected. With more data and a shorter prediction range, the forecast limits will become narrower; thus, the possibility of statistically finding the same reductions in fatalities attributable to the treatments will become larger.

Assuming the distribution of predictive fatalities to be approximately normal, there is approximately a 1.2% probability that the death toll in 2010 after completion of all four treatments at the 50% implementation level will be equal to or less than 553, which is a 40% reduction from the 2004 level (see Figure 14). Therefore, even with the four engineering countermeasures being implemented very aggressively, reductions larger than or equal to 40% are very unlikely. This implies that the four engineering improvements need to be supplemented by other crash countermeasures such as legislative measures to reduce fatalities appreciably.

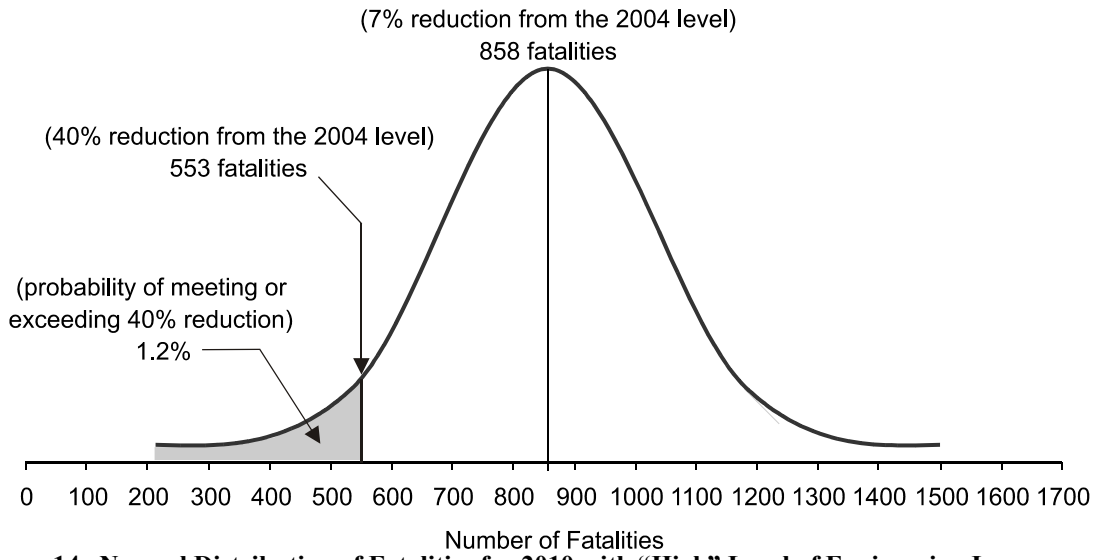
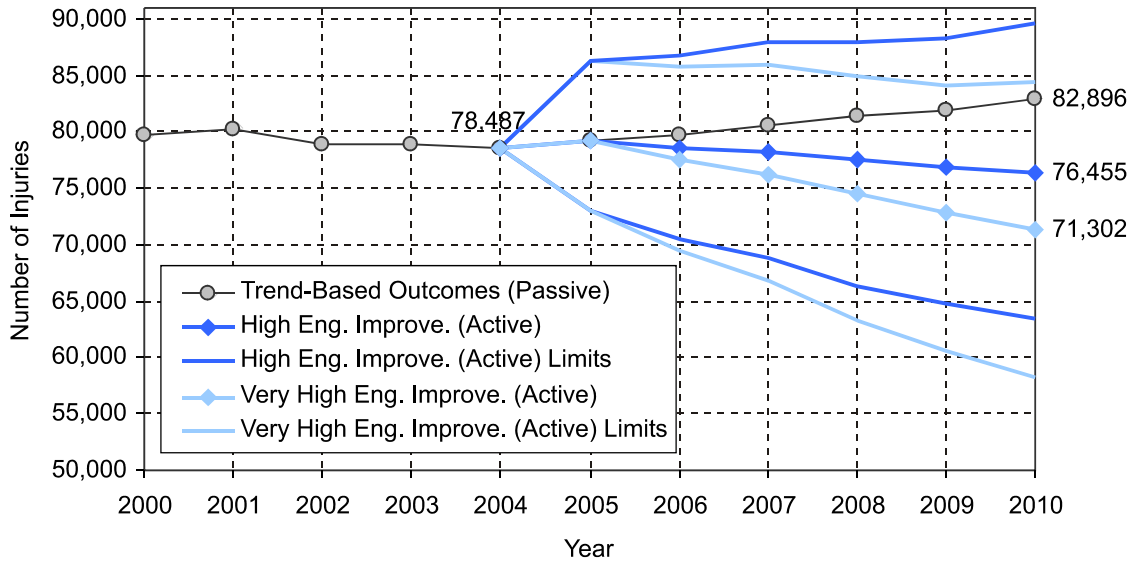


Figure 14. Normal Distribution of Fatalities for 2010 with "High" Level of Engineering Improvement

Injuries

With the assumption of gradual safety improvements as a result of the four engineering treatments over a 5-year period (i.e., 20% execution of the implementation level each year), Figure 15 presents forecast injuries and their probability limits. The two implementation levels as in the fatality case were applied: *High* (50%) and *Very High* (90%). Based on the forecasts from Scenario 1 (trend-based outcomes), two injury forecasts and their probability limits were constructed.



Note: Forecast limits are constructed at the 95% confidence level and do not account for uncertainty in reductions due to the engineering treatments.

Figure 15. Reduced Injury Forecast Attributable to Engineering Treatments

The 50% implementation from 2006 through 2010 is expected to reduce injuries by 2.6% from the 2004 injury level (and 8% from the 2010 trend-based outcomes) by the end of 2010. The percentage of reduction from the 2004 level is small relative to that from the 2010 level because the number of injuries in 2010 under Scenario 1 was forecast to increase by about 6% from the 2004 level. It is very possible that the forecast percentage of 2.6% will lie between –14.2% (i.e., 14.2% increase) and 19.3% at a 95% confidence level.

The reduced number of injuries resulting from the 50% implementation is not statistically proven to be attributable to the treatments; this is suggested by the fact that the 2004 and 2010 levels were within the 95% forecast limits of the *High* level, as was also the case with the *Very High* level.

However, as noted with the fatalities, the combination of the collection of more data in the future along with a shorter forecasting time range will result in narrower prediction limits; thus, there will be a greater chance to detect statistically the same amount of change in injuries that would be attributable to the treatments.

Assuming that the forecasts of injuries are distributed approximately normally, the probability that the injury level is equal to or below 60% of the 2004 injury level with the completion of all four treatments at 50% implementation is only 0.012 % (see Figure 16). In other words, meeting or exceeding the 40% reduction goal with only the four treatments is very unlikely to happen. This implies that in order to reduce injuries significantly, other safety improvement programs such as legislative measures should be executed along with engineering improvements.

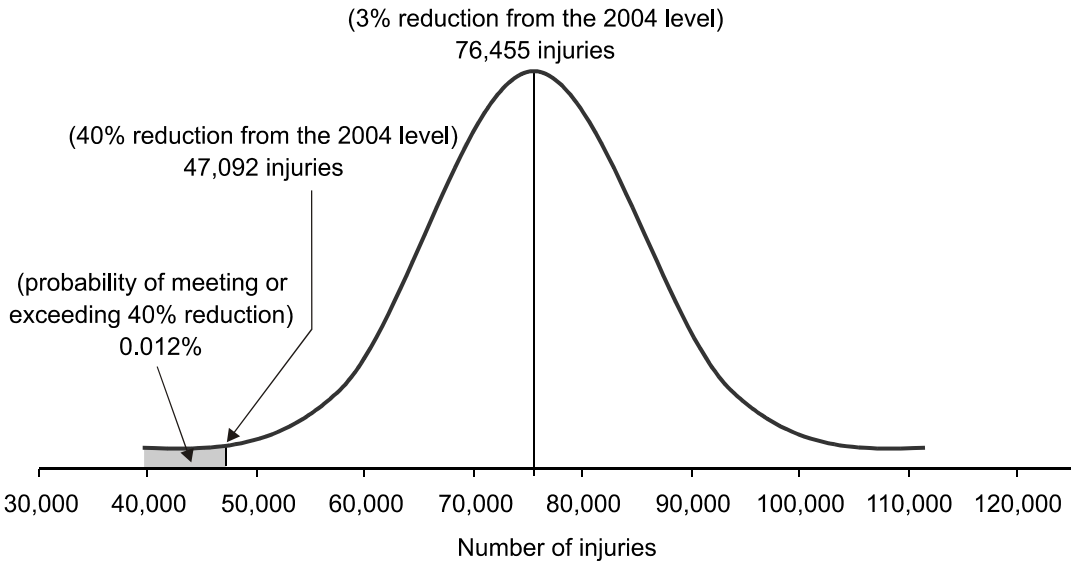


Figure 16. Normal Distribution of Forecast Injuries in 2010 with "High" Level of Engineering Improvement

Summary

After all four engineering treatments have been implemented at the *High* 50% level by the target year of 2010, fatalities and injuries are forecast to decrease by about 7% and 3%, respectively, from the 2004 levels. These percentages are very likely to be between –18.7% and 29.2% for fatalities and –14.2% and 19.3% for injuries. The reductions of 7% and 3% cannot be statistically attributed to the four treatments with the 2004 data being the most recent; however, it may be possible with the data that will be collected for the future years because of smaller forecasting prediction errors (i.e., narrower forecast limits) thanks to more data points and a shorter forecasting range. Based on the assumption of the normal distributions of the forecast fatalities and injuries in 2010, meeting or exceeding the 40% reduction goals is unlikely with the four engineering treatments alone. Other safety plans such as perennial statewide safety education and/or stricter or new traffic safety law are required to reduce fatalities and injuries significantly by 2010.

Scenario 3: Legislative and Engineering Interventions (Active)

Legislative Intervention and Its Effect

As suggested in Scenario 2, it is very difficult for the engineering treatments alone to lead to considerable reductions in fatalities and injuries. Thus, for Scenario 3, a primary enforcement seat belt law is added to the four engineering measures to see what cumulative effect might be expected with respect to an increase in safety. A literature review identified many studies related to primary enforcement seat belt laws. The studies showed that the following are the safety effects resulting from primary enforcement of seat belt usage:

Effects of Primary Enforcement of Seat Belt Use on Fatalities and Injuries

- 7% reduction in driver death rates per billion VMT by changing from secondary to primary enforcement in 10 U.S. states (Charles and Williams, 2005)
- 8% median decrease in occupant fatalities when compared to secondary law (Shults et al., 2004)
- 13% reduction in occupant fatalities and a 95% seat belt use rate by changing from secondary to primary enforcement in Washington State (Salzberg and Moffat, 2002)
- 4% reduction in injuries but no change in fatalities by changing from secondary to primary enforcement in California (Houston and Richardson, 2002)
- reduction in fatalities for occupants aged 65 and over in Alabama by changing from secondary to primary enforcement (Grabowski and Morrisey, 2002)
- reduction in fatalities by 3% to 14% in primary law states than in secondary law states (Dinh-Zarr et al., 2001)
- reduction in fatalities in California by 16 % for 5 months after changing to a primary enforcement law (Ulmer, Preusser, and Preusser, 1995).

Effects of Primary Enforcement of Seat Belt Use

- higher use rate in primary law states than secondary law states in general (Glassbrenner, 2005)
- 9% increase in primary seat belt law states than in secondary law states (Houston and Richardson, 2005)
- 14% increase in median seat belt use rate by changing to primary seat belt law in California, Louisiana, Maryland, Oklahoma, Michigan, and Washington, D.C. (Shults et al., 2004).
- increases of 8% to 18% in Maryland, Oklahoma, and the District of Columbia by changing from secondary to primary enforcement (Solomon, Preusser, and Nissen, 2001)
- increase to 83.5% in Michigan by changing from secondary to primary enforcement (Eby, Vivoda, and Fordyce, 2002)
- 8.6% increase in the states with full implantation of "Click It or Ticket" programs, which is a short-duration seat belt enforcement program heavily relying on paid media advertisement (Solomon, Ulmer, and Preusser, 2002)
- increases coincident with a shift to primary enforcement: 52% to 68% in Louisiana and 50% to 62% in Georgia (Cosgrove and Preusser, 1998)
- increase in Louisiana from 52% to 68% in the 6 months after shifting to primary law (Preusser and Preusser, 1997)
- increase in California from 58% to 76% for 5 months after shifting to primary law (Ulmer, Preusser, and Preusser, 1995).

These studies show that shifting seat belt enforcement from secondary to primary increased seat belt use rates, thereby reducing fatalities and/or injuries (or their rates). However, none of these studies provided exact cases that can be directly used for this analysis because the fatalities and injuries must include *all* persons in traffic accidents for this study, not just drivers

(Charles and Williams, 2005) or older persons (Grabowski and Morrisey, 2002) or occupants of the automobile (as opposed to pedestrians) (Shults et al., 2004; Salzberg and Moffat, 2002).

Notwithstanding these issues, the findings of two recent studies (Salzberg and Moffat, 2002; Houston and Richardson, 2002) can be applied to this study. Reductions of 13% in occupant fatalities and 4% in injuries were adopted here as somewhat optimistic cases. In addition, the safety effect reported by Shults et al. (2004), which was an 8% reduction in fatalities, was used for providing more realistic goals. After accounting for the two reduction percentages (13% and 4%), the forecasts of fatalities and injuries were adjusted.

However, it should be noted that the forecasts of reduced injuries and fatalities are based on the assumption that the response of Virginians to primary seat belt enforcement would be comparable to the response of the individuals in the studies of Salzberg and Moffat and Houston and Richardson. In addition, an immediate and continuing impact by conversion to the primary law is assumed upon the passage of the law in 2006.

Engineering Interventions and Their Effects

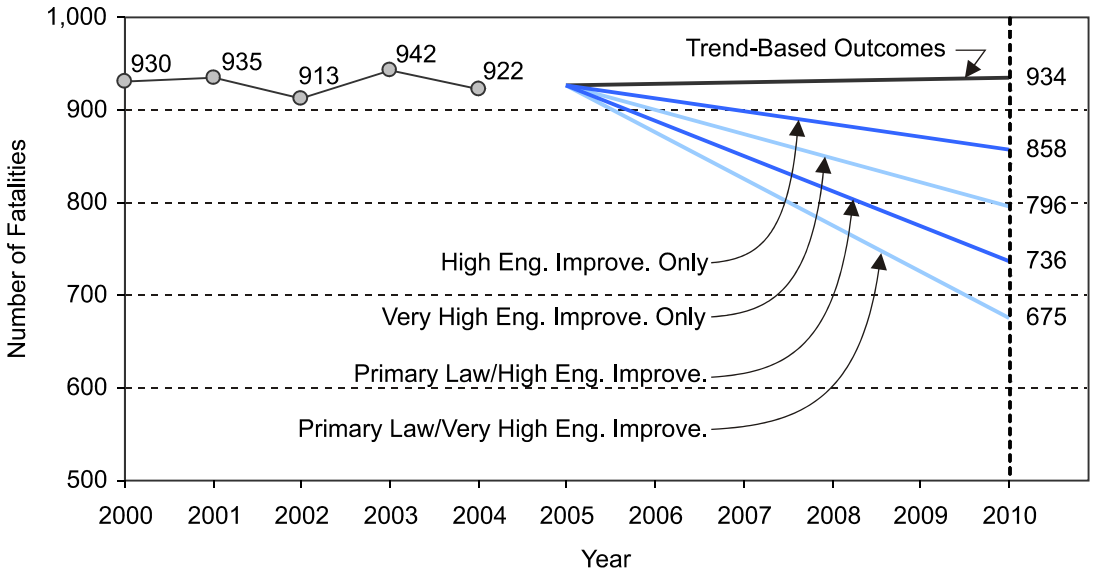
As in Scenario 2, the following four treatments are assumed to be implemented gradually during the years 2006 through 2010: (1) adding exclusive left-turn lanes at an intersection, (2) modifying signal change intervals, (3) installing centerline rumble strips, and (4) installing or upgrading guardrails. However, they are now teamed up with the primary seat belt enforcement.

As for the implementation of the treatments, the two levels considered in Scenario 2 were adopted here: *High* and *Very High* engineering improvements indicate 50% and 90% of the facilities being improved by the treatments, respectively. Concerning the safety effects of the treatments, CRFs in Table 1 are applied and their assumptions in Scenario 2 should come with them naturally. Although both 50% and 90% deployment levels are used for forecasting fatalities and injuries, improvements in 90% of facilities using the four treatments appear to be impractical, and the *High* engineering improvement is still an optimistic and very aggressive level. Thus, the *High* improvement level is mainly used for discussion in Scenario 3.

In summary, forecasts of fatalities and injuries are made under the assumption that the primary seat belt law is passed in 2006, and the corresponding enforcement is executed immediately upon passage of the law, and the four engineering treatments are gradually deployed from 2006 through 2010 with completion of the implementation by the end of 2010.

Fatalities

Assuming a 13% reduction in fatalities attributable to the primary law and reductions attributable to the treatments indicated by CRFs in Table 1, Figure 17 displays possible reduced fatalities that Virginia is likely to experience with the primary law and the engineering treatments, and it also shows the results of Scenario 2. Limits were generated but not displayed in order to maintain visual simplicity. The straight lines for scenarios under two implementation levels in Figure 17 are constructed by linking the forecast for 2005 and each forecast for 2010



Note: Uncertainty in reductions due to the primary law and the engineering treatments are not taken into account.

Figure 17. Reduced Fatality Forecast Attributable to Primary Seat Belt Law and "High" Engineering Improvement in 2010

corresponding to each scenario under two levels. Thus, the points between 2005 and 2010 do not represent forecasts from the final model but a simple linear trend to reach the forecast for 2010.

As seen in Figure 17, when the engineering treatments are in effect jointly with the primary seat belt law, quite significant reductions can be expected. For example, the *High* level of engineering improvements along with the primary seat belt law is forecast to reduce fatalities in 2010 by about 20% from the 2004 level. With the *Very High* level of engineering improvements (90% implementation level), the reduction is expected to be 27%. However, again, this *Very High* level of improvements is impractical, and a 50% level would still be very aggressive and optimistically high in practice.

Reductions of 20.2% in 2010 from the 2004 level (and 21.2% reductions from the 2010 trend-based level) are expected for the primary seat belt law/*High* level of engineering improvements scenario in Figure 17. However, the percentage reduction is very likely to be between –5.5% (5.5% increase) and 42.3%.

Assuming a normal distribution of the forecast fatalities, the probability of reducing the fatalities in 2010 by at least 40% from the 2004 level was calculated to be 8.6% (see Figure 18). This means that a 40% reduction in fatalities is not likely to take place in 2010 even with the primary seat belt law coupled with the implementation of the four engineering treatments at the *High* (50%) level. Thus, to cut the number of fatalities significantly by 2010, additional legislative and/or executive measures such as an unprecedented statewide public education campaign for traffic safety or drastically elevated police enforcement efforts against traffic violators would need to be implemented.

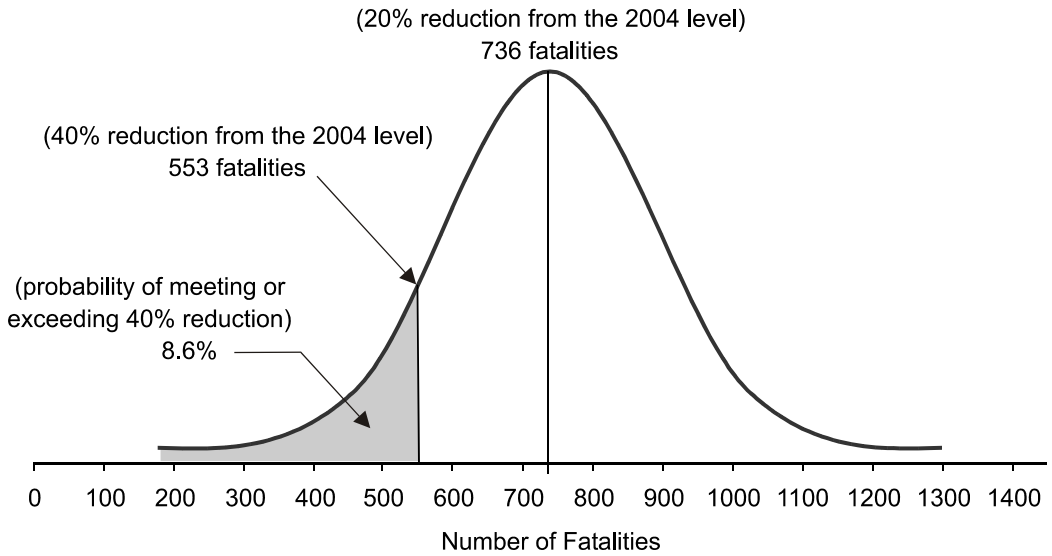


Figure 18. Normal Distribution of Fatality Forecast for 2010 with Primary Seat Belt Law and *High* Engineering Improvements

As stated before, the 50% level of implementation is still believed to be a very aggressive and optimistic level in reality. Thus, the 20% reduction forecast under the 50% level of implementation and with the 13% reduction in fatalities by the primary seat belt law might be considered as the maximum feasible reduction. For a practically achievable reduction in fatalities, the 20% and 30% levels were employed. In addition, instead of the 13% reduction attributable to a primary seat belt law, the 8% reduction reported as a median reduction in the United States was applied (Shults et al., 2004; NCHRP, 2006).

The expected fatalities in 2010 are 814 and 829 under the 20% and 30% implementation levels for engineering treatments, respectively, both with the primary seat belt law assumed to reduce fatalities by 8%. These forecasts correspond to 12% and 10% reductions from the 2004 level of fatalities, respectively. Figure 19 reflects these forecasts.

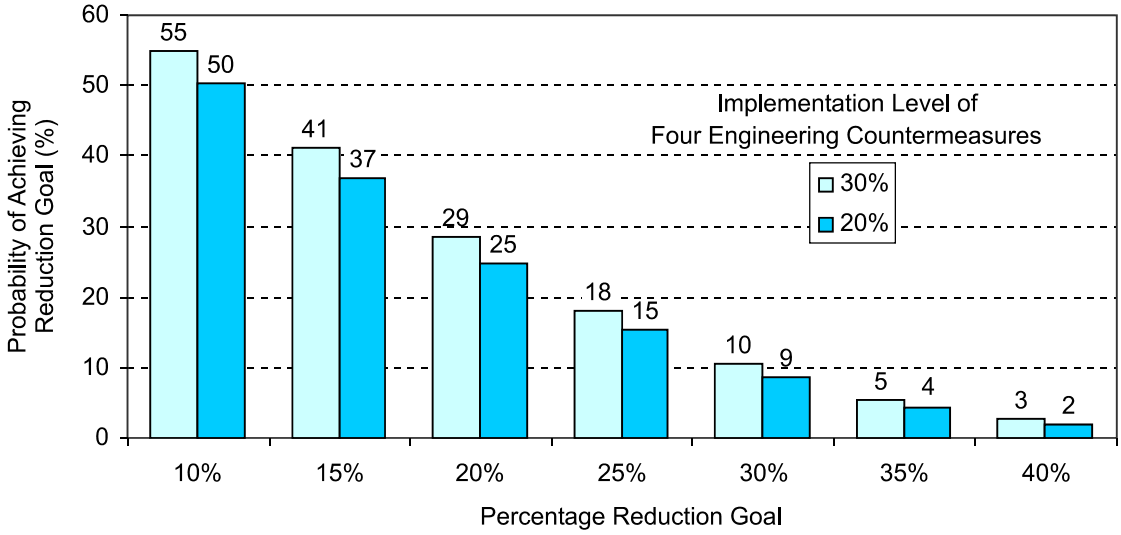


Figure 19. Probability of Achieving Different Reduction Goals in Fatalities for 2010 with a Primary Seat Belt Law and 20% and 30% Implementation Levels of Four Engineering Treatments

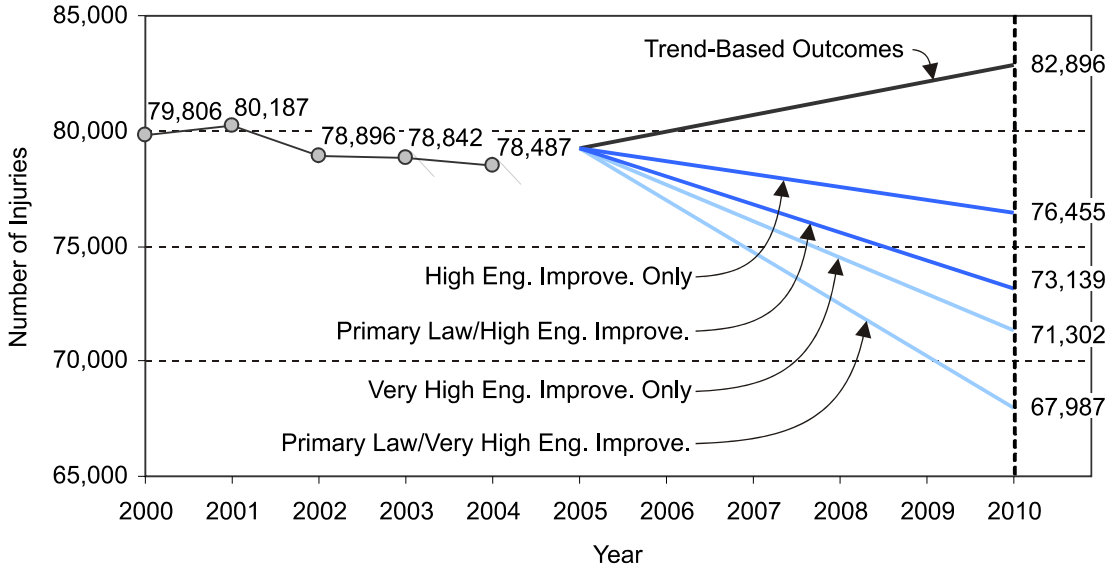
Figure 19 shows the probabilities that different reduction goals will be achieved with the primary seat belt law under the two implementation levels (20% and 30%). It seems that a 10% reduction is likely to be achieved and a 20% reduction is possible with probabilities of between 25% and 30%. A 20% reduction that was expected under the 50% level of implementation with the primary seat belt law reducing fatalities by 13% can be viewed as the upper limit of the realistic reduction goal. Therefore, based on these considerations, the realistic reduction goal is 10% with a maximum of 20%.

Injuries

Figure 20 presents injury forecasts for Virginia under the assumption of a 4% reduction in injuries due to the primary seat belt law and the reductions suggested in Table 1 attributable to the four engineering treatments. Forecasts including only the engineering treatments (i.e., Scenario 2) are overlapped. Forecast limits are not provided to avoid visual confusion. As explained in the fatality case, the straight lines in Figure 20 represent simple linear trends to reach the forecasts in 2010 under different scenarios with two implementation levels.

Compared to the 2004 injury level, the reductions are relatively small; for example, a 7% reduction attributable to the primary seat belt law and *High* engineering improvement. However, compared to the 2010 trend-based level forecast with the assumption of no major safety improvement, the reductions are somewhat large, e.g., a 12% reduction attributable to the primary seat belt law and *High* engineering improvement.

Reductions of 6.8% from the 2004 level are expected for the primary seat belt law/*High* engineering improvement scenario in Figure 20. However, the reduction percentage is very likely to be between –9.9% (9.9% increase) and 23.5% at the 95% confidence level.



Note: Uncertainty in reductions due to the primary law and the engineering treatments are not taken into account.

Figure 20. Reduced Fatality Forecast Attributable to Primary Seat Belt Law and *High* Engineering Improvements

Assuming the forecast of injuries follows a normal distribution, there is less than a 1% probability that there will be a 40% or greater reduction in injuries as a result of the primary seat belt law and the four engineering treatments at the *High* implementation level (50%) (shown in Figure 21).

This means that a 40% reduction in injuries is not likely to take place in 2010 even with the primary seat belt law coupled with the 50% level of implementation of the four engineering treatments. To reduce injuries considerably by 2010, other legislative and/or executive measures in addition to the primary seat belt law and the four treatments would need to be implemented aggressively.

The 7% reduction forecast under the *High* 50% implementation level might be considered as the upper limit of the feasible reduction in injuries. For a practically achievable reduction goal, the 20% and 30% levels were used and a 4% reduction in injuries attributable to a primary seat belt law was retained. The expected injuries in traffic crashes in 2010 are 75,716 and 77,004 under the 20% and 30% levels, respectively. These forecasts correspond to 4% and 2% reductions from the 2004 level, respectively.

Figure 22 shows the probabilities that different goals in reducing injuries can be achieved under the 20% and 30% levels. It seems that about a 5% reduction is likely to be achieved and a 10% reduction is possible with probabilities of between 21% and 25%. A 7% reduction that was expected under the 50% implementation level can be viewed as the upper limit of the realistic reduction goal. Considering these findings, the realistic reduction goal in injuries is 5% with 10% being a maximum.

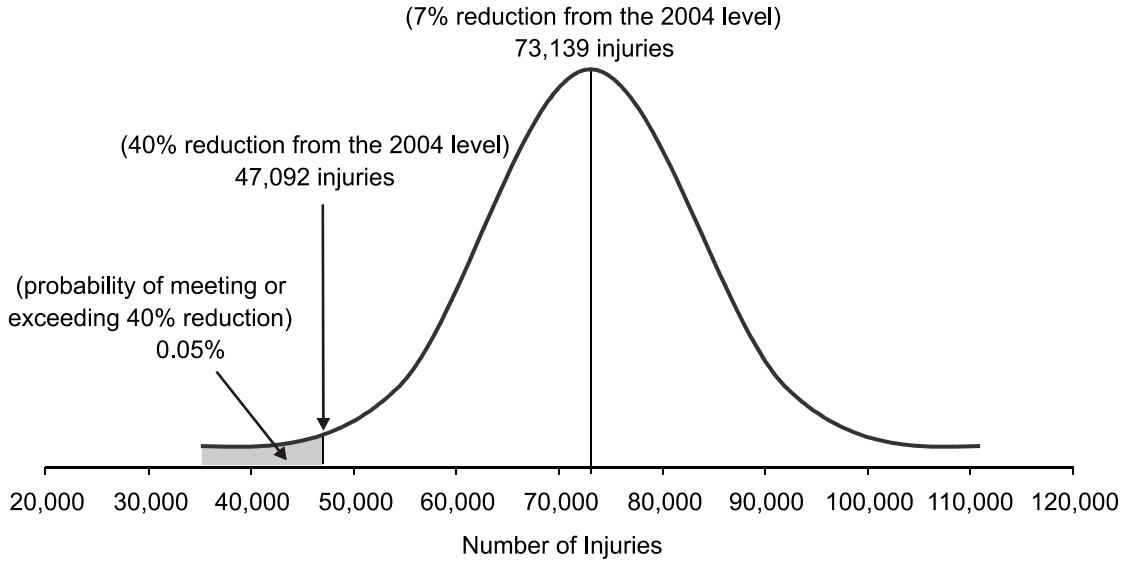


Figure 21. Normal Distribution of Injury Forecast for 2010 with Primary Seat Belt Law and *High* Level of Engineering Improvements

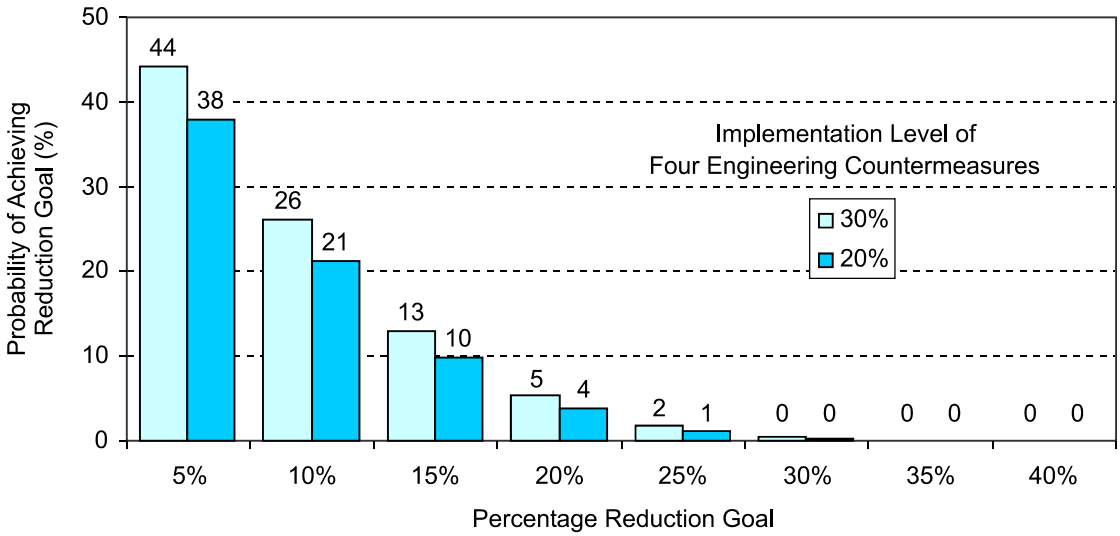


Figure 22. Probability of Achieving Different Reduction Goals in Injuries for 2010 with Primary Seat Belt Law and 20% and 30% Implementation Levels of Four Engineering Treatments

Summary

With the enactment of the primary seat belt law in 2006 and the *High* level of implementation of the four engineering treatments by 2010, about 20% and 7% reductions from the 2004 levels are forecast for fatalities and injuries, respectively. However, these percentages are very likely to vary between –6% and 42% for fatalities and –10% and 24% for injuries. Assuming normal distribution of the forecast fatalities and injuries in 2010, meeting or exceeding the 40% reduction goals is unlikely to occur even with passage of the primary enforcement law and the aggressive deployment of the four treatments. This is especially true for injuries.

Assuming 20% and 30% implementation levels of the four engineering treatments and an 8% decrease in fatalities attributable to the primary seat belt law, more realistic goals were suggested. For fatalities, 10% is recommended for the reduction goal, with a maximum of 20%. For injuries, 5% is recommended for the goal, with a maximum of 10%.

CONCLUSIONS

- *Based on the forecasts in 2010 under three scenarios, the 40% reduction goals for fatalities and injuries are overly optimistic.* Assuming a normal distribution of the forecasts, the probabilities of achieving 40% reduction goals for fatalities and injuries are very low or low. Under Scenario 2, assuming that the four engineering treatments were implemented at the 50% level, the probabilities that Virginia would achieve 40% reductions in 2010 are 1.2% for fatalities and 0.012% for injuries. Under Scenario 3, assuming that the primary enforcement seat belt law was enacted *and* the four engineering treatments were implemented at the 50% level, the probabilities that Virginia would achieve 40% reductions in 2010 are 8.6% for fatalities and 0.05% for injuries.

- *Under Scenario 2 at the 50% implementation level for the four engineering treatments, a moderate reduction in fatalities and a small reduction in injuries are forecast for 2010.*

About 7% and 3% reductions in 2010 from the 2004 levels are forecast for fatalities and injuries, respectively. However, the reduction percentages are very likely to lie between –19% (19% increase) and 29% for fatalities and –14% (14% increase) and 19% for injuries.

- *Under Scenario 3 at the 50% implementation level for the four engineering treatments, a somewhat large reduction in fatalities and a moderate reduction in injuries are forecast for 2010.* About 20% and 7% reductions from the 2004 levels are forecast for fatalities and injuries in 2010, respectively. However, the reduction percentages are very likely to lie between –6% (6% increase) and 42% for fatalities and –10% (10% increase) and 24% for injuries.

- *Under Scenario 3 with the 20% and 30% implementation levels for the four treatments and a median reduction (8%) in fatalities attributable to a primary seat belt law, a moderate reduction in fatalities and a small reduction in injuries are forecast for 2010.* A 10% to 12% reduction in fatalities and a 2% to 4% reduction in injuries from the 2004 levels are expected.

RECOMMENDATIONS

1. *A moderate reduction goal for fatalities and a low reduction goal for injuries in 2010 are recommended for Virginia*. Accounting for a slight increase in fatalities and injuries in 2010 compared to 2004, a 10% reduction goal (with a maximum of 20%) for fatalities and a 5% reduction goal (with a maximum of 10%) for injuries are recommended as realistic goals for Virginia. These goals assume that Virginia enacts a primary enforcement seat belt law and exercises enforcement efforts accordingly and deploys engineering crash countermeasures comparable to the 20% to 30% implementation level for the four engineering treatments described in this study.

2. *Forecasts in fatalities and injuries in 2010 should be updated as new data years become available to incorporate any change in the temporal pattern of fatalities and injuries and to monitor how Virginia is doing in meeting the goals.* The forecasts and goals are based on the assumption that the temporal pattern uncovered by the models using the past data remains unchanged for future years. Newly available data might help form a slightly different pattern, leading to different forecasts. Even if the forecasts were in line with the old forecasts, they could help fine-tune confidence intervals so that more precise forecasts could be obtained.

ACKNOWLEDGMENTS

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APPENDIX A. ARDL AND ARIMA MODELS

Autoregressive Distributed Lag (ARDL) Model with Autoregressive Errors (ARDL-AR)

When a regression model applies to time-series data, its residuals are usually correlated over time, which is a serious violation of the independent error assumption of a regression analysis. This violation brings about serious consequences to regression results, including incorrect statistical significance and inefficiency of parameter estimates.

A linear regression model with a lagged dependent variable can account for autocorrelated errors through the lagged dependent variable. This model is considered as a case of an autoregressive distributed lag (ARDL) model. An ARDL model with a lagged dependent variable is written as follows (modified from the Eq. (17-23) in Green [2000]):

$$y_t = \mu + \sum_{i=1}^{g} \gamma_i y_{t-i} + \sum_{j=0}^{r} \beta_j x_{t-j} + \sum_{k=1}^{m} \delta_k w_{k,t} + \varepsilon_t,\ \varepsilon_t \sim IN(0,\sigma^2)$$

where t is a time index, y_t is a dependent variable at time t, y_{t-i} is a distributed dependent variable with i lags, x_{t-j} is a distributed independent variable with j lags, $w_{k,t}$ is a set of independent variables with no lag at time t, i is a lag distribution indicator of a dependent variable (i=1,…,g), k is a indicator for independent variables (k=1,…,m), j is a lag distribution indicator of independent variables (j=0,…,r), μ is an intercept, γ_i is a coefficient of the lagged dependent variable, β_j is a set of coefficients of the lag-distributed independent variables, δ_k is a set of coefficients of independent variables, and ε_t is a independently and normally distributed error with mean zero and variable σ^2.

This model is denoted ARDL(g,r) to specify the orders of the two polynomial lags, dependent lags and independent lags. The autocorrelation model (ARDL(1,1) with a restriction of $\beta_1 = -\gamma_i \beta_0$) and the classical regression model (ARDL(0,0)) can be viewed as special cases of an ARDL model (Green, 2000).

However, when an error term ε_t of an ARDL model is serially correlated, it is superimposed on lagged dependent variables rendering them interdependent with error terms. Therefore, such a model violates two key assumptions (i.e., independent errors and exogenous explanatory variables) of a regression analysis simultaneously, and its ordinary least squares estimates are biased and inconsistent.

In such a case with *autoregressive* errors, the problems with estimates can be resolved by applying an autoregressive model to the error part of the ARDL model. The model specification can be expressed as follows:

$$y_t = \mu + \sum_{i=1}^{g} \gamma_i y_{t-i} + \sum_{j=0}^{r} \beta_j x_{t-j} + \sum_{k=1}^{m} \delta_k w_{k,t} + v_t \text{ and } v_t = \sum_{l=1}^{p} \phi_l v_{t-l} + \varepsilon_t,\ \varepsilon_t \sim IN(0,\sigma^2)$$

where v_t is an correlated error term at time t, ϕ_l is a set of autoregressive parameters, l is a lag index (l=1,…p), and the rest of terms are defined the same as in the previous equation. Since a

terminology for this model is not established, it is denoted here as ARDL(g,r)-AR(p) to indicate two polynomial lag orders (g,r) and one autoregressive order (p).

The models used for this study can be expressed much more simply because they do not contain any independent variable (r=0). The final model specifications for fatality and injury are written as follows:

ARDL(1,0)-AR(0) for fatality: $fatality_t = \mu + \gamma \cdot fatality_{t-1} + \varepsilon_t$, and

ARDL(1,0)-AR(1) for injury: $injury_t = \mu + \gamma \cdot injury_{t-1} + v_t$ and $v_t = \phi_1 v_{t-1} + \varepsilon_t$

where $\varepsilon_t \sim IN(0, \sigma^2)$.

In the development of the final models, first, the model only with the dependent variable at lag 1 was estimated. Then, the Durbin h-test was performed to see if there is any remaining autocorrelation in residuals of the model. The residuals were found to be serially correlated by the test. Therefore, an autoregressive error model was employed to remove the autocorrelation in the errors. In order to determine the order of the model, a stepwise autoregression was utilized. Lags 0 and 1 were found to be appropriate for fatalities and injuries, respectively. SAS PROC AUTOREG was used to perform all estimation and testing procedures (PROC PDLREG produced the same model estimation results).

Meanwhile, an ARDL(1,0)AR(p) model, model with one lagged dependent variable with lag 1 (g=1), a set of independent variables with no lag (r=0), and autoregressive error terms with lag p, can also be derived from an autoregressive error model with a lagged dependent variable.

For future (i.e., out-of-sample) prediction, a simulation technique should be employed for a model with a lagged dependent variable due to dynamic nature. For prediction limits, Monte Carlo simulation technique is employed.

AutoRegressive Integrate Moving Average (ARIMA) Model

An ARIMA model is generally conceded to be the most popular among time-series models. It uses a linear combination of past values and past errors (also called shocks or innovations) using historical data to uncover patterns and predict future values. Box and Jenkins in 1976 systemized an ARIMA model that was first developed in 1960s, thus the model is often referred to as a Box-Jenkins model.

A typical ARIMA model without seasonality is usually denoted by ARIMA(p,d,q) and expressed as follows:

$$(1-B)^d Y_t = \mu + \frac{\theta(B)}{\phi(B)} \varepsilon_t$$

where t indexes time, Y_t is a response time-series, μ is a mean term, B is the backshift operator ($BY_t = Y_{t-1}$), $\phi(B)$ is an autoregressive operator, represented as a polynomial in a back shift operator: $\phi(B) = 1 - \phi_1 B - \cdots - \phi_p B^p$, $\theta(B)$ is a MA operator, represented as a polynomial in a

back shift operator: $\theta(B) = 1 - \theta_1 B - \cdots - \theta_q B^q$, ε_t is a random error, and p, d, q are the orders of an autoregressive part, a MA part and a differencing.

The final ARIMA model specifications for fatality and injury are written as follows:

ARIMA(0,1,0) for fatality: $(1-B)\,fatality_t = \mu + \varepsilon_t$, and
ARIMA(0,1,(2)) for injury: $(1-B)injury_t = \mu + (1-\theta_2 B^2)\varepsilon_t$ (also called IMA(1,(2)))

Each of the ARIMA parameters (p,d,q) in the above models was determined in the following way. The differencing parameter (d) was determined by checking stationarity of the time-series. Stationarity can be checked by visual inspection of a data plot against time (e.g., increase or decrease over time indicates nonstationarity) and an autocorrelation function (ACF) plot of the data (e.g., very slow decay in an ACF plot indicates nonstationarity). Both fatality and injury series showed nonstationarity, and their first differenced series showed stationarity, thus the difference parameter was determined to be one (i.e., d=1).

The order of autocorrelation (p) and the order of MA (q) were identified by examining plots of autocorrelation function (ACF), partial autocorrelation function (PACF), and inverse autocorrelation function (IACF). By examining the patterns in the three autocorrelation function plots, no autocorrelation (AR) component appeared to be needed for both fatality and injury models, thus the AR order is zero (i.e., p=0). However, the second order of MA was identified for the differenced injury series (i.e., q=2), while zero order MA was suggested for the differenced fatality series (i.e., q=0). For injuries, because the parameter of the first order MA component turned out to be statistically insignificant, only the second order MA was included for injuries (this kind of the ARIMA models is called a subset model).

Prediction for future time window can be made easily through a forecasting procedure of an ARIMA model, unlike an ARDL-AR model requiring a simulation process for forecasting.

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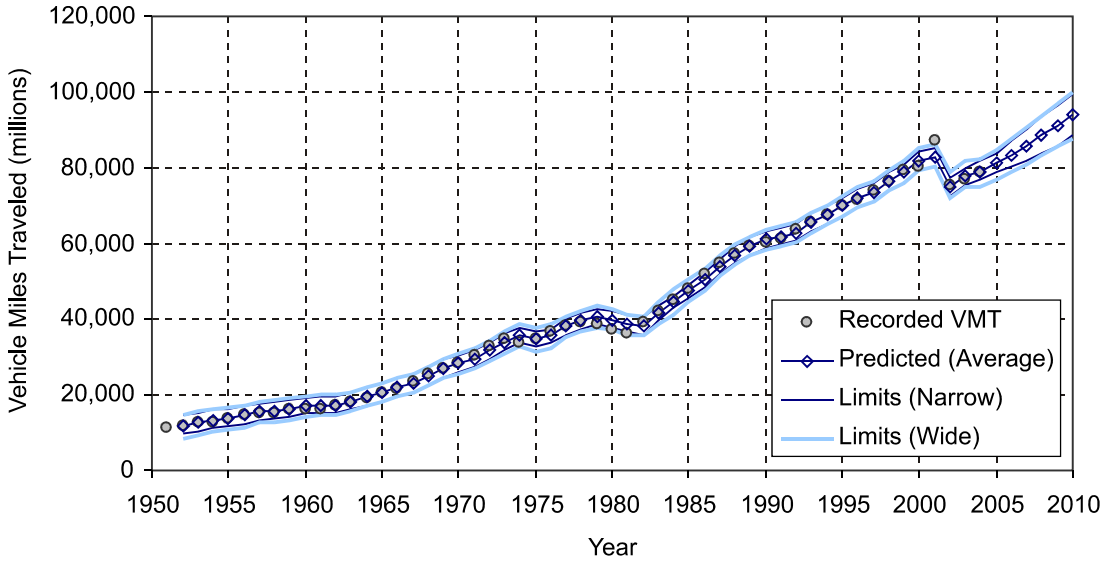
APPENDIX B. FORECASTS OF VEHICLE MILES TRAVELED

The final forecast VMT is shown in Figures B-1 and B-2 along with its confidence limits. VMT in Virginia has grown quite steadily over time with three exceptional periods (around 1975, 1980, and 2001). The decline near 1975 is believed to be due to oil crisis in 1974, and the big drop in 2001 is due to a change of an estimation method for VMT. Two models were used to fit the VMT data: (1) Trend-AR(1,3) model with time, squared time, and an indicator for the VMT estimation method change in 2001, and (2) ARIMA(0,1,0) model with time and the indicator for change in 2001 as input variables. Because of models' fit measures being close to each other, averaging forecasts and using narrow/wide limits were adopted for final forecasts. It should be noted that the forecast models accounted for the change of the VMT estimation method in 2001 in a manner of an abrupt and permanent impact.

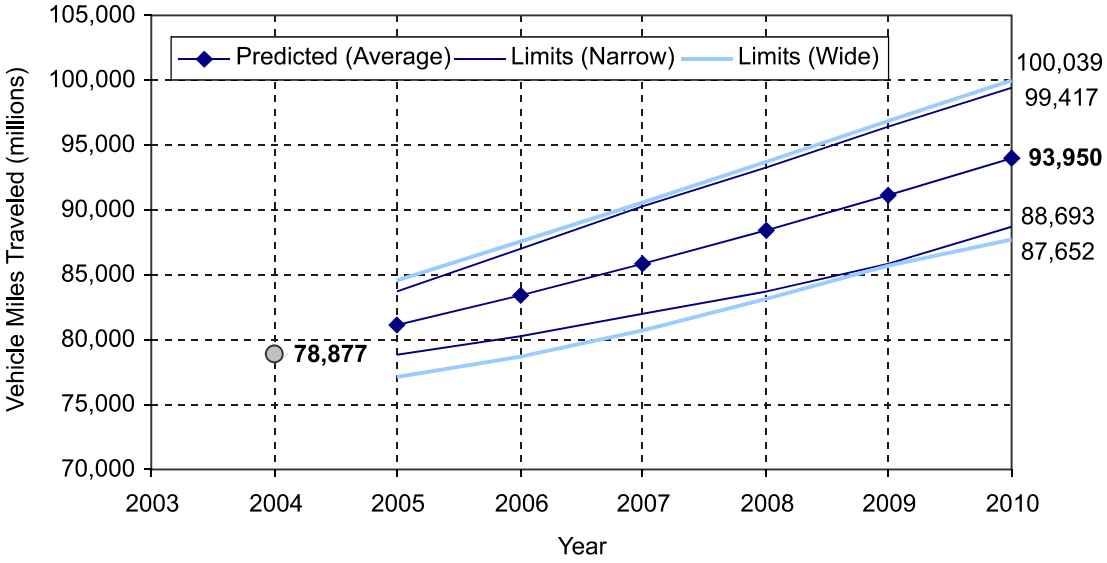
Correctly reflecting the overall upward trend, Virginia VMT is expected to grow and reach at about 94 billion VMT in 2010, compared to about 79 billion in 2004. However, the forecast can range from 88.7 to 99.4 billion, and with the same statistical confidence, can range from 87.7 to 100 billion as an extreme case.

It should be noted that these forecasts were made based on two assumptions. One is that the pattern of VMT changes in the past stays in the near future, and the other is that there would be no change in policy or condition in state level or national level significantly affecting Virginians' driving behaviors.



Note: Prediction limits are constructed at the 95% confidence level.

Figure B-1. Final Vehicle Miles Traveled Forecasts for Virginia, Entire Period



Note: Prediction limits are constructed at the 95% confidence level.

Figure B-2. Final Vehicle Miles Traveled Forecasts for Virginia, 2005-2010

APPENDIX C. ACCIDENT EXPOSURES VERSUS FATALITIES AND INJURIES

Table C-1. Fatality versus Four Accident Exposures

Variable	With VMT		With Population		With Driver		With Vehicle	
	Coeff.	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**
Constant	1003	<0.001	1667	<0.001	1392	<0.001	1025	<0.001
VMT[1]	**-2.97E-4**	**0.870**[2]	NA	–	NA	–	NA	–
Population	NA[3]	–	**-1.09E-4**	**<0.001**	NA	–	NA	–
Driver	NA	–	NA	–	**-9.60E-5**	**<0.001**	NA	–
Vehicle	NA	–	NA	–	NA	–	**-9.74E-6**	**0.676**
AR(1)	-0.818	<0.001	-0.527	0.0014	-0.379	0.0297	-0.815	<0.001

Note: The dependent variable is the number of annual fatalities.
[1]VMT is in millions.
[2]Shade indicates statistical non-significance at the 0.1 level.
[3]Not applicable.

Table C-2. Injury versus Four Accident Exposures

Variable	With VMT		With Population		With Driver		With Vehicle	
	Coeff.	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**
Constant	-1134	0.732	141757	0.022	-38410	0.006	-2309	0.756
Time[1]	–	–	4089	0.013	5986	<0.001	1081	0.022
Time-square	–	–	–	–	-57.26	<0.001	-31.45	<0.001
VMT[2]	**2.152**	**<0.001**	NA	–	NA	–	NA	–
VMT-square	**-1.40E-5**	**<0.001**	NA	–	NA	–	NA	–
Population	NA[4]	–	**-0.037**	**0.063**	NA	–	NA	–
Driver	NA	–	NA	–	**-0.00725**	**0.412**[3]	NA	–
Vehicle	NA	–	NA	–	NA	–	**0.017**	**0.02**
AR(1)	-0.393	0.004	-0.523	<0.001	–	–	-0.637	<0.001
AR(2)	-0.429	0.005	–	–	-0.421	0.019	–	–
AR(4)	0.345	0.007	–	–	0.494	0.005	0.240	0.05

Note: The dependent variable is the number of annual fatalities.
[1]Time = Year – 1951.
[2]VMT is in millions.
[3]Shade indicates statistical non-significance at the 0.1 level.
[4]Not applicable.

APPENDIX D. FINAL MODEL SPECIFICATIONS AND ESTIMATES

Table D-1. Final Prediction Models for Fatality

Fatality Models		ARDL(1,0)-AR(0)		ARIMA(0,1,0)	
		Coef.	**Std. Err.**	**Coef.**	**Std. Err.**
Model Estimates	Constant	162.93	78.21	-1.453	10.12
	$Fatality_{t-1}$	0.835	0.0779	NA[6]	–
	Num. of obs.	53		53	
Goodness-of-fit Measures	MSE[1]	5090		5431	
	MAPE[2] (%)	5.88		6.19	
	AIC[3]	604.73		607.19	
	SBC[4]	608.67		609.16	
	R^2 [5]	0.693		0.666	
Model Specification		$fatality_t = 162.9 + 0.835 \cdot fatality_{t-1}$ (<0.001)[7]		(1-B) $fatality_t = -1.453$	
Estimation Technique		FIML[8]		CLS[9]	

[1]Mean Square Error: $MSE = \frac{1}{n}\sum_{t=1}^{n}(y_t - \hat{y}_t)^2$

[2]Mean Absolute Percent Prediction Error: $MAPE = \frac{100}{n}\sum_{t=1}^{n}\left|(y_t - \hat{y}_t)/y_t\right|$

[3]Akaike's Information Criterion: $AIC = n\ln(MSE) + 2k$

[4]Schwarz Bayesian Information Criterion: $SBC(or\ BIC) = n\ln(MSE) + k\ln(n)$

[5]Coefficient of Determination: $R^2 = 1 - \sum_{t=1}^{n}(y_t - \hat{y}_t)^2 \Big/ \sum_{t=1}^{n}(y_t - \bar{y}_t)^2$

[6]Not applicable.

[7]*P* values of coefficient parameters.

[8]FIML: Full Information Maximum Likelihood.

[9]CLS: Conditional Least Square.

Table D-2. Final Prediction Models for Injury

Injury Models		ARDL(1,0)-AR(1)		ARIMA(0,1,(2))	
		Coef.	**Std. Err.**	**Coef.**	**Std. Err.**
Model Estimates	Constant	2294	1196	982	727
	$Injury_{t-1}$	0.978	0.020	NA	–
	AR(1)	-0.279	0.137	NA	–
	MA(1,2)	NA[6]	–	0.407	0.128
	Num. of obs.	53		53	
Goodness-of-fit Measures	MSE[1]	14944078		14590830	
	MAPE[2] (%)	4.52		4.81	
	AIC[3]	1028.95		1026.65	
	SBC[4]	1034.86		1030.59	
	R^2 [5]	0.968		0.968	
Model Specification		$injury_t = 2294+0.978\ injury_{t-1}–0.279\ v_{t-1}$ (<0.001)[7] (0.05)		(1-B) $injury_t = 982+e_t+0.407e_{t-2}$ (0.002)	
Estimation Technique		FIML[8]		CLS[9]	

[1]Mean Square Error: $MSE = \frac{1}{n}\sum_{t=1}^{n}(y_t - \hat{y}_t)^2$

[2]Mean Absolute Percent Prediction Error: $MAPE = \frac{100}{n}\sum_{t=1}^{n}\left|(y_t - \hat{y}_t)/y_t\right|$

[3]Akaike's Information Criterion: $AIC = n\ln(MSE) + 2k$

[4]Schwarz Bayesian Information Criterion: $SBC(or\ BIC) = n\ln(MSE) + k\ln(n)$

[5]Coefficient of Determination: $R^2 = 1 - \sum_{t=1}^{n}(y_t - \hat{y}_t)^2 \Big/ \sum_{t=1}^{n}(y_t - \bar{y}_t)^2$

[6]Not Applicable.

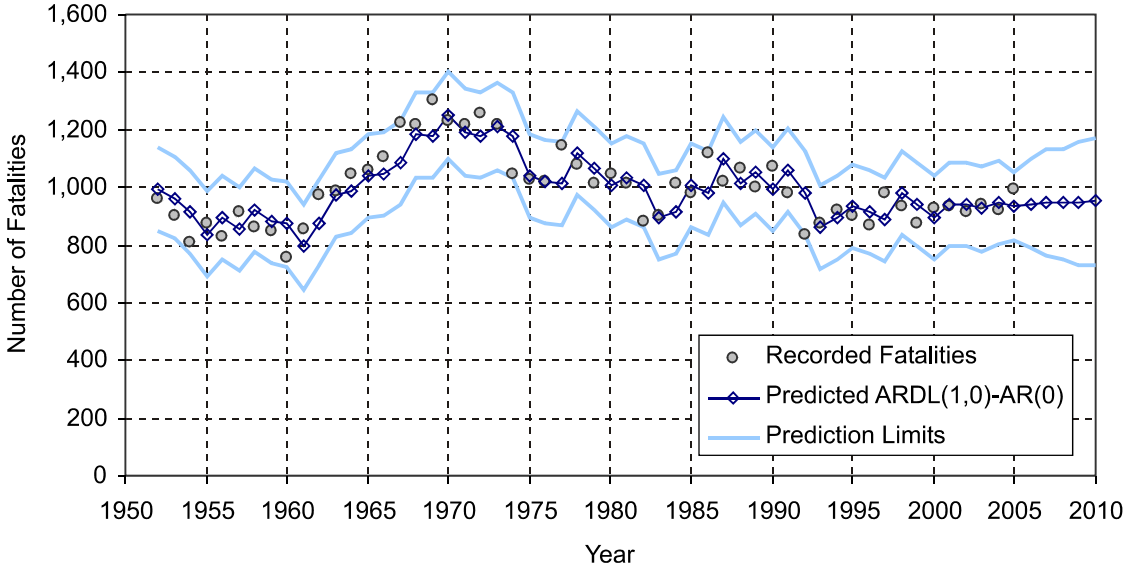
[7]P-values of coefficient parameters.

[8]FIML: Full Information Maximum Likelihood.

[9]CLS: Conditional Least Square.

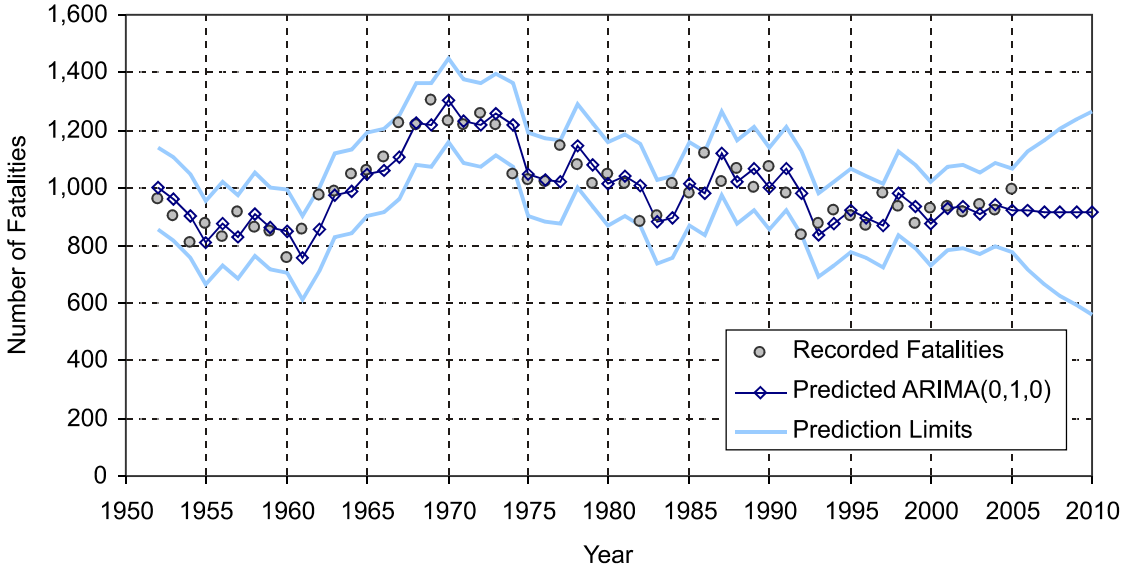
APPENDIX E. FORECASTS BY MODEL

Fatality Forecasts



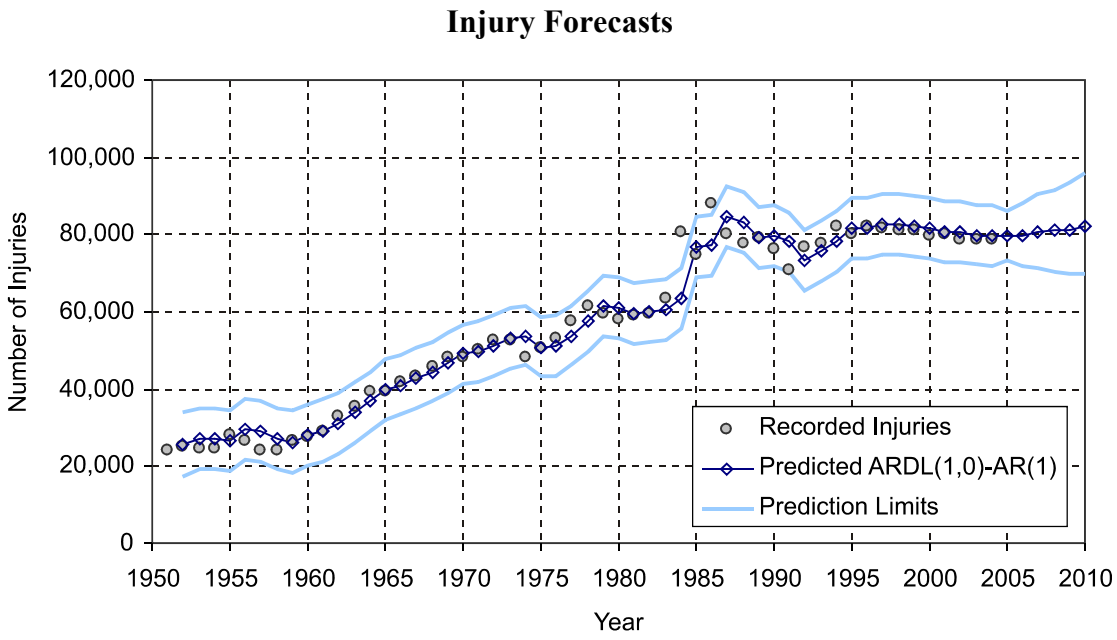
Note: Prediction limits are constructed at the 95% confidence level.

Figure E-1. Forecasts of Fatalities in Virginia by ARDL Model



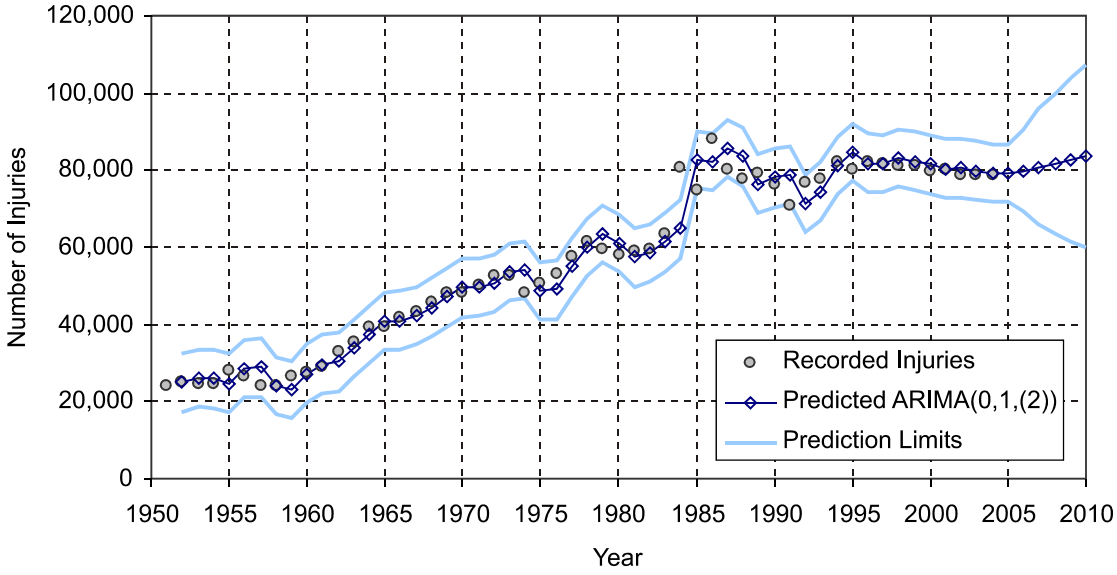
Note: Prediction limits are constructed at the 95% confidence level.

Figure E-2. Forecasts of Fatalities in Virginia by ARIMA Model



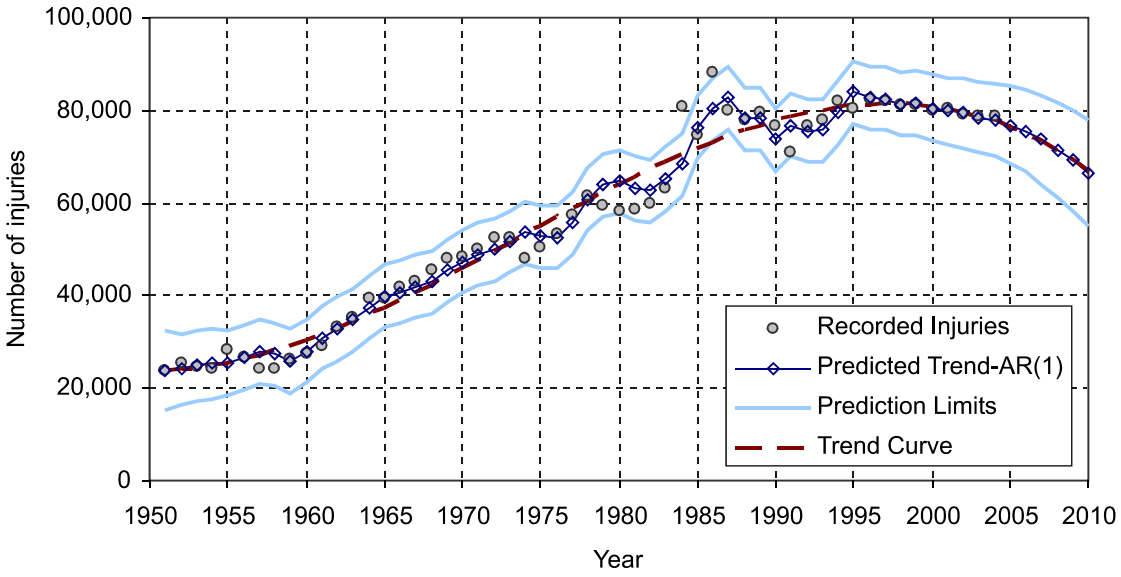
Note: Prediction limits are constructed at the 95% confidence level.

Figure E-3. Forecasts of Injuries in Virginia by ARDL Model



Note: Prediction limits are constructed at the 95% confidence level.

Figure E-4. Forecasts of Injuries in Virginia by ARIMA Model



Note: Prediction limits are constructed at the 95% confidence level.

Figure E-5. Forecasts of Injuries in Virginia by Trend Model