TOOLS FOR ASSESSING SAFETY IMPACT OF LONG-RANGE TRANSPORTATION PLANS IN URBAN AREAS

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ABSTRACT

The evaluation and comparison of alternative long-range transportation plans should include the safety implications of respective plans. However, the commonly available tools for safety analysis, specifically crash prediction models, require detailed information that is not dealt with by the long-range forecasting process. Therefore, transportation planners need simplified crash prediction models based on variables for which long-range forecasts are available. This research examines the availability of such models. The difficulties of developing crash prediction models are identified and the results of an attempt to develop simple models are presented. These models were applied in a case study in which the number of crashes were predicted for several alternative long-range land use and transportation scenarios developed for the urbanized area of Eugene-Springfield, Oregon. The results of the application along with various issues encountered are presented.

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INTRODUCTION

The Transportation Equity Act for the Twenty First Century (TEA-21) identified seven planning factors that should be addressed in the metropolitan planning process. One of these deals with the safety and security of motorized and non-motorized users of the transportation system. This recognition of the importance of 'safety and security' has led to several research activities. Early on several workshops and case studies were performed. Most of these activities was sponsored by the Federal Highway Administration (FHWA). Soon it was apparent that most of the Metropolitan Planning Organizations (MPO) does not take into account the safety consequences of alternative long-range transportation plans adequately. Usually it is only at the project level that safety and security issues are addressed by MPOs and other agencies. (1)

One reason for the inability of MPOs to assess objectively the safety consequences of alternative transportation system plans is the lack of analytical tools. Although highway safety engineers have developed a variety of mathematical models for predicting crashes on highway segments and at intersections, these models require detailed data. The application of these models are difficult because the explanatory variables that are commonly used or needed for these models require detailed site specific information, which generally is not available for long-range transportation system plans. There is a need for developing appropriate safety analysis tools for the use in long-range planning. This paper presents the findings of a search for these tools, which was undertaken at the University of Tennessee (UT). This study also developed a set of simple models for planning level application, which are presented. The experiences gained during the development of the models are discussed.

Following the model development work, a case study application was performed. The findings of this case study are presented in the latter section of the report.

CRASH PREDICTION WORKSHOPS

In order to obtain the views of practitioners in the field of urban transportation planning and assess the state of the art with regard to incorporating safety considerations in long-range planning, two one-day long workshops were organized – one in Raleigh, NC, and the other in Portland, OR. The major observations made by the participants of these workshops are presented below.

Workshop in Raleigh, NC

The workshop was held on November 16, 2001. There were approximately 20 participants from various public agencies including the FHWA offices in North Carolina and Washington D.C., North Carolina Department of Transportation, Capital Area Metropolitan Planning Organization, North Carolina State University, University of Tennessee, and representatives of a few engineering consulting firms.

The beginning portion of the workshop consisted of a general session with three presentations from two engineering consultants and a representative of the FHWA in Washington D.C. The presentations were followed by two group workshops, one discussing Corridor Level Planning and the second discussing Long Range Systems Planning issues, each with a designated participant as Recorder and Editor. The participants were separated into two groups for this purpose and the groups later switched these two discussion topics. Thus every participant attended workshops on both topics.

Workshop in Portland, OR

The Oregon Workshop, which was held on May 20, 2002 focused on the identification of practical approaches to assess the safety impacts of long-range transportation plan scenarios. The workshop was held in Portland at Oregon Department of Transportation (ODOT) Region 1 Headquarters. The staff of Eugene-Springfield area's MPO, Lane Council of Governments (LCOG), assisted UT researchers in organizing this workshop. There were 13 people in attendance. A wide range of expertise was in attendance at the workshop. Representation cut across various levels of government – federal, state, regional – as well as a cross section of relevant expertise – regional policy analysis and planning, regional transportation modeling, traffic safety analysis, crash data management. The attendees included both practitioners and researchers. The group discussed the possibility of testing crash prediction models using actual data and scenarios used in the development of long-range transportation plans in the Eugene-Springfield area by Lane Council of Governments (LCOG).

General Findings of Workshops

1. There are issues and difficulties concerning the availability and quality of crash data collected by different agencies. The data available at the state level usually are of higher quality than those available at the local level. However, in some states local MPOs have difficulty in obtaining crash data from state agencies. Further, crash data are more complete for urban state highways, which usually are arterial roads, than for collector and local roads. Complete data on pedestrian and bicycle crashes also may not be available in many areas.

2. The participants believed that the available crash prediction models are applicable to corridor level analysis for which detailed data for the highways usually are developed. However, the detailed data requirement of these models is not compatible with the scope of long-range transportation planning.

3. Many of the workshop participants noted that ideally an MPO, when building the alternative plan scenarios, should employ a set of safety principles to consciously increase the inherent safety of the alternatives. With regard to the measurement of safety impacts of long-range alternatives, it was suggested that the impacts be quantified and compared on a relative basis based on macro-level exposure measures at the network level. Past crash data could be analyzed to establish macro-level relationships. For example, an analysis of 4-lane versus 5-lane road cross-sections, or the impact of Transportation Demand Management (TDM), or a nodal development pattern should be done with the objective of understanding their potential for crash reduction. Safety related exposure levels of alternative plans should be established based on an understanding of the tradeoffs of alternative roadway configurations, the differences among various roadway classifications, interchanges versus intersections, the impacts of TDM and land use measures, etc. Overall, it is important to understand the potential for safety improvement on different parts of the transportation system and to focus resources on those areas with the highest potential for improvement. In addition to investments on roadway improvements, other land use and transportation planning decisions, e.g., TDM and nodal development, can affect the overall safety of a given planning scenario by:

a) Establishing the basic form of urban development and the roadway network characteristics as a whole;
b) Affecting the amount of travel and selection of mode.

4. An issue was raised regarding the ability to establish a general set of measures or a forecasting methodology that would be applicable to urban areas of all sizes, in all parts of the country. It was recognized that if a robust set of generalized relationships could not be established, a common approach and a model formulation might be identified for the development of an accident prediction model unique to each specific urban area. Researchers in British Columbia, Canada, are in the preliminary stages of developing such an approach and model formulation. They also are developing macros for using these models with the EMME/2 software for travel demand forecasting.

CRASH PREDICTION MODELS AND THE CHALLENGE

A crash prediction model can have different alternative forms -- simple or complex. It can be in the form of a cross-classification table (matrix) where the cell values are crash/accident rates and the classification is based on different factors, or variables, such as the type of roadway, traffic volume, roadway geometry, driveway density, etc. These matrices can vary in complexity depending on the number of factors used for cross-classification. These tabulated rates can be plotted as two or three-dimensional graphs and smooth curves can be fitted through the plotted points, if desired.

Another approach is to derive mathematical equations by correlating crash rates, or number of crashes, with different explanatory/independent variables using a statistical technique such as multiple regression analysis. Whatever may be the form of the equation, these models are developed based on historical crash data. Crash rates are based on the number of crashes and an appropriate exposure measure. Separate models usually are developed for road segments and intersections, which themselves can be separated by different classes or types. It should be pointed out that regression models may use "number of crashes" as the dependent variable instead of 'crashes rates'; and in that case 'vehicle-miles traveled' is used as an independent variable.

One of the advantages of the cross-classification approach is that it avoids the mathematical formulation of an equation. However, this approach can be somewhat crude because the values of the variables used for cross-classifying the crash rates must be grouped into categories using specific ranges of values. Further, the selection of variables to use for cross-classification usually is done intuitively, and the strength of correlation of individual independent variables with the crash rates, the response/dependent variable, usually is not determined. Of course, statistical procedures such as an analysis of variance can be performed to determine if the relationship among the variables is significant or not. A prediction model in the form of an equation requires a rigorous statistical analysis for identifying the appropriate variables and their strength of the relationships. The underlying statistical distributions may be simple or fairly complex, such as Normal, Poisson, or Negative Binomial.

Whichever approach may be used for developing a crash prediction model, it is extremely important for the purpose of long-range forecasting that forecast values are available for the explanatory or independent variables used. This requirement must be considered when selecting the variables to be used; otherwise, the model may not be useful if later it is found that forecasts of a certain variable will not be available. Another important requirement for the models to be used for planning is that the independent variables used are meaningful for planning purposes. These variables should deal with the options and issues involving alternative plans or scenarios that are to be assessed with the help of the model.

The dilemma that a model developer faces when developing a crash prediction model for long-range planning is that the variables that have been found to have significant correlation with crash rates deal with detailed road features, which may not represent meaningful issues in the context of alternative long-range transportation plans. For example, the characteristics of horizontal curves usually are found to have a strong correlation with crash rates along a highway.

However, long-range transportation plan alternatives usually do not deal with such specific geometric features.

Long-range issues addressed by alternative plans usually involve proposals for new freeways, new or expanded public transit services, and alternative land use patterns. Travel demand forecasting models can generate values for such variables as vehicle-miles traveled, travel speed and level of traffic congestion expressed in terms of volume/capacity ratios. A major issue and challenge, therefore, is to develop crash prediction models based on independent variables that are usually available and used in the long-range planning process, and finding statistically sound and reliable relationships with these variables presents a challenge.

Examples of Crash Prediction Models

As discussed in the earlier section, the format or structure of crash prediction models can vary widely. Most of the state departments of transportation (DOT) develop crash rates in terms of crashes per 100 million vehicle-miles for different types of roads, and the road 'types' are based on general geometric features and/or administrative designation. These rates are based on statewide data for three years and include both urban and rural areas. This type of rates can be developed exclusively for urban areas and functional classes can be used instead of administrative route designation.

A software program developed by researchers at Texas Transportation Institute known as Micro-BENCOST for the purpose of economic assessment of alternative highway projects incorporates tables of crash rates for estimating the number of crashes by severity (fatal, injury, and property damage only). (2) The crash rates for injury crashes for roadway segments included in Micro-BENCOST are presented in Table 1. Similar tables are included for other types of segment crashes (Fatal and Property Damage Only) as well as for different types of intersections. These cross-classification tables reflect the following relationships:

a. For Roadway Segments: Number of crashes per 100 million VMT is related to a highway's number of lanes, access control, and traffic volume (groups).
b. For Intersections: Number of crashes per 100 million entering vehicles is related to traffic volume going through an intersection.

A paper by Poole and Cribbins presents the crash rates for highway segments used by North Carolina DOT's (NCDOT) Statewide Planning Branch. (3) These rates are cross-classified according to functional class and volume to capacity ratio (V/C). These relationships developed by NCDOT indicate that freeways generally are safer than non-freeway highways and for each functional class the crash rates increase as V/C ratio increases. The V/C ratios are calculated using daily (24 hour) traffic volume and daily capacity. (It should be noted that due to the manner in which 24-hour capacity is commonly calculated, these V/C ratios in effect may reflect peak hour V/C ratios.) NCDOT's crash rates for highway segments include both non-intersection and intersection crashes.

A paper by Persaud presents a model, which is similar to the model formulation being used by researchers of the University of British Columbia. (4) The independent variables used by this model are just ADT and 'section length'. The model formulation is as follows:

$$\text{Number of crashes on a road section} = \text{Section Length} * a1\,(ADT)^{b1}$$

The coefficient 'a1' and the exponent 'b1' of the model were found to depend on the class of road. This model is very applicable for long-range planning since future ADT values for individual sections/links of a future road network are predicted with the help of travel forecasting models, and the classes of different roads in the future also are known.

Whereas the above described crash prediction models designed to be used for planning purposes incorporate variables for which data are generally available, the models used by traffic engineers and highway safety engineers use several variables that are not usually available for long-range future plans. For example, a model developed by Harwood, et al, for predicting the number of non-intersection crashes on two-lane rural highway segments uses the following independent variables and more (5):

- Average Daily Traffic
- Lane and shoulder widths
- Driveway density
- Roadside hazard rating
- Horizontal curve lengths and radii
- Vertical curve lengths and 'A' values

The same researchers, Harwood, et al., also developed a crash prediction model for intersections on rural highways. (5) The independent variables used in this model include the following:

- Average Daily Traffic
- Roadside hazard rating
- Exclusive right turn lane
- Angle of intersection
- Driveways on approaches
- Protected phases of traffic signals
- Left turn percentages
- Grades
- Percent trucks

For many of the above listed variables long-range forecasts are difficult to generate in the context of transportation systems planning. If these types of models are to be used to quantify the safety consequences of alternative transportation systems plan for 20 years in the future, a great deal of effort has to be expended for developing the values for each of the independent variables for every link and node of a network, and this task is formidable.

INITIAL EXPERIENCE WITH CRASH PREDICTION DATA ANALYSIS

In the beginning of the project, the researchers at the University of Tennessee (UT) analyzed two sets of crash data for developing crash prediction models for planning applications. Crash data were obtained from Knox County in Tennessee, which includes the city of Knoxville. Similar data were obtained from NCDOT for three counties where the urban areas of Charlotte, Raleigh and Greensboro are located. The respective data sets covered a period of three years. The crashes were assigned to specific roadway segments based on their locations. Several characteristics of each road segment including traffic were included in the data set. Intersection crashes were not separated from the others and these were allocated to the nearest segment, and thus each segment's crash data included both intersection related and mid-block crashes. The crash rates were developed for 'Fatal', 'Non-Fatal Injury', and 'Property Damage Only' categories, and also for 'Total' number of crashes.

A cross-classification analysis of crash rates based on different factors such as functional classification of roadways, volume/capacity ratios, traffic volume groups, and number of lanes was performed. The cross-classification that resembles the scheme used by Poole and Cribbins (3) did not show the same pattern as found by them. Unlike the curves developed by them, the crash rates did not follow a consistent pattern of variation. For example, the rates did not increase uniformly with an increase of either traffic volume or volume/capacity ratio, and the rates were found to fluctuate widely.

Several forms of multiple regression equations also were developed. In all these cases many of the variables were transformed into corresponding 'logarithmic' forms in order to reflect a non-linear relationship. In general the correlation indicator 'R-squared' for total crash rates were found to have acceptable values of nearly 0.5. However, the relationships of crashes with some of the variables were not what one would expect intuitively. Also it was found that there were many 'zero' observations for 'fatal' crashes, and this caused difficulties for statistical analysis.

REVISED APPROACH AND MODELS

After the somewhat disappointing results of the initial analysis with data from Knox County and North Carolina counties, it was decided that intersection crashes be separated from mid-block crashes. A new set of data was developed from two urbanized areas in Tennessee – Knox and Davidson counties, which include the cities of Knoxville and Nashville respectively. This data set included crash data covering a three-year period and was organized in two separate files – one for non-intersection and the other for intersection crashes. It should be pointed out that for freeways all crashes were included as non-intersection (or segment) crashes; interchange related crashes were not separated from others.

These data were analyzed first by developing a classification scheme for segments as well as for intersections, and then calculating crash rates for each class. Segments were classified according to geometric features and traffic volumes of roads. Intersections were classified according to the type of the major highway (of the two intersecting roads) and the type of intersection traffic control. In addition to crash rates, regression models were developed using the same cross-classification scheme. The results of these two types of analysis – rates and regression equations -- are presented in the following sections.

Crash Rates

Segment Crash Rates

The cross-classification scheme for non-intersection (i.e. segment) crashes was to group the crash rates (number of crashes per million VMT) of individual road segments into categories based on general geometric characteristics and traffic volume of respective segments. Then for each category an average value of the rates was calculated. The rates for 'Fatal and Injury' (F&I) crashes and also those for 'Property Damage Only' (PDO) are presented in Table 2. The variations of these crash rates according to geometric features follow a pattern that intuitively may be expected except in a few cases. For example, for a specific volume group, freeways have the lowest crash rate even though it included all crashes, i.e., interchange related crashes were not separated. Further, the rates for divided highways (non-freeway) are lower than those for undivided segments and roads with two-way left turn lanes in most cases.

The analysis revealed an interesting pattern of non-intersection crash rates for the F&I crashes for each type of roads. It was found that these rates generally have a declining trend with increasing traffic volumes. The same pattern was not as clearly evident in the case of POD crash rates. A graph of segment crash rates for all types of crashes combined is presented in Figure 1, and these graphs show an overall declining trend of rates with increasing traffic volume.

Intersection Crash Rates

The crash rates for intersections, which were classified according to the type of the major road and intersection control, are included in Table 3 and presented in graphical form in Figure 2. These rates presented some difficulties for intuitive interpretation. Intersection crash rates for F&I crashes as well as PDO crashes were higher for signalized intersections in general than non-signalized intersections for all volume groups. Commonly, signalized intersections are expected to have lower rates for F&I crashes although their rates for PDO crashes may be higher than the corresponding rates for non-signalized intersections. One pattern of crash rates that was noted with a few exceptions is that intersection crash rates decreased with increasing magnitude of entering volume, which is a measure of exposure.

Regression Models for Segment (Non-Intersection) Crashes

The data for Davidson County and Knox County were used also for developing regression models for crash prediction based on a systematic process consisting of several steps. (The classification scheme for the segments was the same as that used for crash rates.) First, the constant one was added to the number of crashes to avoid deleting zero crash observations. The crashes were grouped into three types – total accidents, injury plus fatal accidents and non-injury (property damage only) accidents to develop separate models for each type. Then natural logarithm was taken of the resulting variable 'number of crashes + 1' to make the relationships linear. The number of crashes used was the total for a three-year period.

Second, within a highway type (freeway, undivided, divided, two-way left turn lane (TWLTL), or two-lane) the observations that were to be flagged as outliers were the same across the models for different types of crashes. M-estimation robust regression models and various single-case outlier diagnostics (such as the external studentized residual, hat diagonal, Cook's index, and the degree of fit standardized) were used to flag suspicious observations. Specific focus was on observations that contaminated the prediction ability of the models. As a rule, there were only two or three such outliers for each highway type, except for the undivided highways where five outliers were noted.

Third, the significance of coefficients was noted. The coefficients for AADT (noted at aadt2 in Table 4) and segment-length (noted as seg-leng in Table 4) were always significant across all models.

Fourth, the normality of the residuals was checked. The residuals for undivided highway and two-lane highway models were not usually normal, but a bootstrapping approach for the coefficients of the models still found them very significant.

Fifth, randomness in the residual patterns was desired, but occasionally there was a hint of pattern, as in the case of the injury plus fatality model for undivided highways.

Sixth, an overall assessment of the model's predictability was made from the R^2 and the Press R^2. The Press R^2 is a model validation measure that looks at the predictive ability of a model when each observation is singularly deleted from the model and the remaining n-1 observations are used to predict the one held out. This process is repeated n times and the corresponding R^2 is called the Press R^2.

An examination of the R^2 and the Press R^2 for the different highway types in Table 4 shows that the predictability of the freeway models was the best followed by the left-turn models. In every case, the Press R^2 was at least 90% of the R^2, indicating good prediction. The seventh step in the strategy was to look at the prediction ability of the model for a single observation with AADT being 10,000 (10K in the database) and segment-length being 0.5 miles.

The individual forecast for this case with AADT being 10K and segment-length being.5 miles is shown in Table 3 under the forecast column. One should notice that the forecast for non-injury accidents added to injury plus fatality accidents does not exactly equal the forecast for total accidents. They are close but not exactly equivalent. Of course, to make a forecast with any of these models one would insert 10 (AADT in thousands) and 0.5 miles into the model, take the anti-logarithm of the resulting number, and then subtract one from that number.

Finally, there are some subtleties in the coefficient magnitudes in Table 4. For instance, the constant terms in the freeway models are higher than all of the other models, but the coefficients for AADT and segment-length are lower for the freeway models, implying that greater traffic on similar segment-lengths will result in more accidents on non-freeway roads. There is a possibility that one model could have been constructed to characterize all types of highways, but this would have complicated the outlier problem and the prediction assessments. Simplicity was the goal.

In order to see how the models predict total crashes for varying AADT values, the model-generated values of crashes were plotted. This was done for two different segment lengths of 0.5 mile and 1.0 mile respectively and the plot for the 1.0 mile segment is shown in Figure 3.

Figure 1 shows that freeways are safer after approximately 30,000 AADT, and that roads with two-way left-turn lanes and two-lane roads have higher accidents after that same change point. It should be pointed out that for practical reasons each type of roads has an applicable range of traffic volumes. For example, freeways commonly are not built for traffic volumes of less than 30,000 per day. Further in this case freeway crashes included all crashes, whereas those for other highways included only non-intersection crashes. One can conclude based on these graphs that freeways are generally safer in terms of total accidents.

These graphs show that the number of crashes on a segment increases with increasing traffic volume; however, a detailed analysis shows that the crash rate (per MVMT) in the case of freeways actually decreases as ADT increases. For other types of roads the rates were found to either hold steady or increase slightly with increasing traffic volume. These trends of crash rates may not be readily evident from the graphs of Figure 3, and separate graphs were plotted for a few selected roads and rates, which are shown in Figure 4.

Regression Models for Intersection Crashes

Developing reliable models to predict total crashes, non-injury crashes, injury plus fatal crashes, for the intersection data for Davidson and Knox counties was very difficult. Several forms of models were examined. First, the constant one was added to the number of crashes to avoid deleting zero crash observations and then the natural logarithm was taken of the resulting variable to make the relationships linear. Second, Poisson regression models were constructed across the five types of roads. Other variables used in the model were AADT (in 10K), the type of intersection, and sometimes the interaction of these two variables. The conclusion of the model fitting effort is that none of the models was significant for predicting fatalities and only one of the models (for intersections of roads with a two-way left turn lane) had an R^2 better than any of the non-intersection models. This overall poor performance across intersection types, forced one to consider only an overall model for total accidents. The overall model includes categorical variables for highway and intersection types.

The Poisson regression model that best explained total-accidents at intersections is as follows:

Predicted = Exp(1.24216053565362 + .048943016108921*(Hwy_Type=1)

+ .386712026776221*(Hwy_Type=2)

+ .487773305265047*(Hwy_Type=3) + .579358294384216*(Hwy_Type=4)

+ 1.12306728820923*(Int_Type=1) + .638651838437729*(Int_Type=2)

+ 1.07695375179648E-02*aadt)

Highway type, AADT, and intersection type were all significant, and the McFadden's R^2 was 0.2595 (which is different than the typical R^2 in multiple regression). Since the interaction between highway type and intersection type or between either of these two variables and AADT were not considered, any scatter plots would just show parallel lines. Whenever the interactions were considered, there were serious collinearity problems; and the models did not predict any better. Simplicity was a major criterion on model selection.

A CASE STUDY OF CRASH PREDICTION FOR PLAN EVALUATION

Introduction & Methodology

A major objective of the research study was to use crash prediction models for assessing the safety consequences of alternative long-range transportation plans in urban areas. The MPO in Eugene-Springfield, Oregon, area agreed to participate in a case study and apply the models developed by this research study. This case study application is discussed in this section.

In the course of updating the Regional Transportation Plan (RTP) for the Eugene-Springfield area, the Lane Council of Governments (LCOG) developed a series of six alternative plan scenarios to test the effectiveness of various strategies – Travel Demand Management (TDM), Land Use, and Transportation System Changes. To measure the effectiveness of these strategies a series of performance criteria were developed. While safety was one of the broad categories of criteria considered, no safety indicator or measure was found that could be modeled and forecast in a practical manner. This made it difficult to provide policy makers with any measure of the relative safety of the alternative scenarios. The UT study provided an opportunity to explore if safety can be brought into the analysis of scenarios

As reported earlier, UT researchers developed crash rates for non-intersection crashes for different types of highway segments and traffic volume groups. They also developed crash rates for different types of intersections. Further, they developed regression models for non-intersection crashes. This information was based on data from Tennessee. It was decided to use these crash rates for non-intersection and intersection crashes to the case of the Eugene area to test the methodology. The rates based on Tennessee data obviously were not applicable to Eugene. However, their use can reveal technical difficulties of application and also give a relative assessment of safety. So it was decided to obtain output from models of the six alternative plan scenarios, apply the crash rates to the model output, and develop a summary of the analysis.

The non-intersection (segment) crash rates were based on vehicle miles traveled (VMT) and the intersection crash rates were based on 'entering vehicles'. Rates were developed for Fatalities and Injuries combined, and Property Damage Only (PDO) crashes. After forecasting fatalities and injuries combined, and PDOs separately, a total was developed with all three types of crashes combined. As mentioned earlier, the rates were also disaggregated by highway classification and intersection types as well as volume levels. The crash rates developed by UT researchers are presented in Table 2 and 3 respectively.

LCOG had developed six alternative plan scenarios in the course of updating its RTP. These scenarios emphasized different strategy sets drawn from three broad areas – TDM, Land Use, and System Improvements. The scenarios are summarized below:

- The first plan concept, the **Base Case**, is the "business as usual" scenario, representing a projection of current conditions, trends and programs into the year 2015. Because the Base Case did not contain any new projects or innovative strategies, it provided a point of reference from which to gauge the effectiveness of the five alternative plan concepts.
- The next three plan concepts, **Demand Management Emphasis**, **Land Use Emphasis**, and **System Changes Emphasis**, emphasized one category of strategies and assumes lower levels of the other two categories.

- The **Equal Emphasis** plan concept contained relatively balanced levels of strategies from each of the three categories.
- The last plan concept, **TPR VMT Goal Compliance**, contains all the strategies necessary to meet the state's Transportation Planning Rule (TPR) goal of reducing vehicle miles traveled (VMT) by 10% per capita over current conditions by the year 2015.

Route segment VMT and entering vehicle counts were obtained from LCOG's travel forecasting model. Model output was fed into a spreadsheet containing the crash rates. The travel forecast modeling and development of the crash forecasting spreadsheet are discussed in more detail in subsequent sections.

Application of Crash Rates

Purpose and Overall Approach

The region's travel forecasting model was used to provide the TransPlan scenario data for crash rate application. Two types of data were prepared; road segment vehicle-miles and intersection entering volumes. Road segment vehicle-miles were stratified by road type, number of lanes, and road segment volume class. Intersection volumes were be stratified by road type (of the major approach), intersection control type, and entering volume class. We used an aggregate approach, whereby the stratified vehicle-miles and entering volumes were compiled for the entire model network for each scenario, and then the crash rates were applied.

Modeling Methodology

A model roadway network was prepared for a 1995 Base Year, a 2015 Base Case, and for each of five TransPlan scenario alternatives. The first task was to identify roadway types, and store the results in a user-defined link data field (ul1):

Road Type	Description
1	Freeway, 6-lane
2	Freeway, 4-lane
3	Divided, 4-lane (Also used for 1-way couplet classification
4	5-Lane Continuous L.T. (also used for 3-lane)
5	Undivided, 4-lane
6	Undivided, 2-lane

A few adjustments were necessary to adapt the Tennessee rates to Eugene's network. There were no crash rates specific to 3-lane roads, 1-way couplets, or freeway ramps. The 5-lane road type was used for 3-lane sections, since both configurations would be included in the "left turn" category for the intersection crash rate application. One-way couplets were treated as divided 4-lane facilities. Freeway entrance ramps were classified as 4-lane freeway segments. Freeway exit ramps were classified as divided arterial segments. The next task identified intersection types using the road type of the major approach, as determined by the lowest road type among the intersection approaches, and the type of intersection control. The following node attributes types were stored in a user-defined node data field (ui1):

Intersection Control	Description
0	Non-intersection node
1	Local Street Intersection (Not used in crash rate calculations)
2	Signal Controlled Arterial or Collector Intersection
3	All-Way Stop Controlled Arterial or Collector Intersection
4	2-way Stop or No Controls Collector Intersection

The next step determined the appropriate volume classification bin for each road segment and intersection. The network links in the EMME/2 model system are uni-directional. That is, a single 2-way segment is represented by two directional links. Therefore, volume class boundaries were divided in half for link volume classification purposes. In other words, if total roadway volume is 20,000, each directional link was assigned to volume class 5 (16,000 -24,000 ADT), even though each link only carries about 10,000 and would otherwise be in class 4. In so doing, the total roadway VMT (combined directions) is appropriately assigned to volume class 5.

No such adjustment was required for the intersection volume classifications, since only the approach links of each road segment attached to the intersection were considered.

The final step involved calculating the total network link VMT and intersection entering volumes for each roadway and intersection stratification (type by volume class) and outputting the data to an Excel spreadsheet. A series of EMME/2 macros were developed to automate these steps

Model Output

A set of Excel worksheets were used to store the model data. The "Codes" spreadsheet indicates the roadway and intersection classification codes (Table 5). The "Travel Model Data" spreadsheet stores the results of each EMME/2 scenario, which have been output as a columnar listing of 175 scalar (single-cell) matrices (Table 6). The "Formatted Travel Model Output" spreadsheet allows the user to select a scenario for crash rate application, and the scenario results are then automatically formatted for copying to the crash forecasting spreadsheet. (Table 7)

Crash Forecasting Spreadsheet

A spreadsheet was employed to apply crash rates to model output to produce estimates of aggregate crashes for each alternative plan scenario. In several cases, the original set of crash rates needed to be extended to include other volume levels. This is because the distribution of traffic volumes by roadway type were different for Eugene-Springfield and Knoxville (in most cases, Eugene-Springfield's distribution took in the lower traffic volume levels for each roadway type). Tables 8a and 8b contain the full set of crash rates used in this application (extended rates are highlighted).

In each case where an extension was required, the assumption was made to use the last original rate within a given highway classification. For example, a segment crash rate was needed for Divided Highways at a volume level of 4,000 – 7,999 vehicles. The last Divided Highway rate from the original rate table was for the 8,000-15,999 volume level. Rather than presuming a particular extrapolation away from the original rate, that rate was extended back to the 4,000 – 7,999 level. While this does not likely reflect reality, there was no practical means to extrapolate the rates (the rates within any particular classification appear to be non-linear). The approach used to extend the rate tables seemed to be the most conservative given available time and resources.

Table 9 provides an example of how the crash forecasting spreadsheet was set up. For each alternative plan scenario, model output was retrieved from the model output sheet (example shown in Table 7). The extended crash rates were applied to produce a set of forecasted crashes for each highway classification and volume level. As described above, four separate forecasts were developed for each alternative plan scenario:

(1) Segment Fatal plus Injury
(2) Segment PDO
(3) Intersection Fatal plus Injury
(4) Intersection PDO

The sum total of these represents the estimate of crashes (per average weekday) for a given alternative plan scenario. Table 10 illustrates how the individual forecasts for each alternative plan scenario were combined and compared with results from other scenarios. Crash forecasts were aggregated into Segment Totals, Intersection Totals, and System Totals for each scenario.

Summary results were also prepared comparing scenarios by facility type for both intersections and road segments. Table 11 provides these results. The analysis of the comparison by facility type suggests that intersections with signalized left turns and signalized intersections on divided highways experience the highest number of crashes. This is a combination of both the volume of vehicles through these types of intersections and the higher crash rates estimated for these types of intersections.

In a similar analysis, it is the two-lane road segments that experience significantly higher crash levels than other road segment types. This is also a combination of higher volumes and crash rates compared to other road segment types.

Results were also developed to show annual crash levels for each alternative plan scenario. An annualization multiplier of 261 was applied to the average weekday results. These results are presented in Table 12.

Reviewing the System Totals, the analysis would seem to indicate that the 2015 TPR Compliance and TDM Emphasis scenarios produce the lowest aggregate crashes. However, it is not clear that the differences between the scenario estimates are statistically significant. Also, while no technical comparison was done, it appeared that the Knoxville crash rates themselves were probably higher than what would be experienced in the Eugene-Springfield area. These issues are discussed further later.

Use of Regression Models

The University of Tennessee researchers developed a set of regression models in the form of log-linear functions to predict annual number of crashes on road segments of different functional classes. These models are presented in an earlier section (Table 4). Regression models for intersection crashes were also developed, but the strength of correlation of these models was not satisfactory. In order to identify potential problems of application and related issues, the regression models for road segments were applied to the Eugene-Springfield network.

Facility-specific continuous crash functions were far simpler to apply in the network models than the crash rate tables with rates cross-classified by facility type and volume bin. Applying crash rates required two sets of network calculations, the first to place the link or intersection into the appropriate type-volume cell, and the second to apply the rate. Use of continuous functions eliminates the classification process and the need to "look-up" the appropriate crash rate. It enables one to directly calculate and store predicted crashes as a network link (road segment) or node (intersection) attribute.

The specific log-linear segment functions that we used were problematic in several ways. First, they included a constant term. This can result in predicted crashes even on links having no predicted traffic volumes. Furthermore, if a link is split into smaller link segments, the constant results in more predicted crashes on the combined segments, even though the actual road network represented remains the same. We also noted that for many segments, the constant accounted for about 2/3 or more of the total predicted crashes. Secondly, the regression functions used ADT and segment length in an additive expression. This, once again, makes predicted crashes dependent upon the arbitrary number of links representing a road network segment. The more links, regardless of the length of segment represented, the more predicted crashes. This problem can be eliminated by using Vehicle-Miles, or by using separately-weighted ADT and Length in a multiplicative expression.

Assessment of Application

This section summarizes observations made in the process of completing the application effort. These observations are categorized in terms of model output, and crash forecasting.

Model Output Observations

i) Aggregate vs. Disaggregate approaches

The aggregate approach is useful for scenario comparisons, since total predicted crashes by type are an important transportation plan performance measure. This approach only requires that each roadway link and intersection node carry the appropriate classification (road type, traffic control, and volume class). Results are summed for each classification over the entire model network. A disaggregate approach would not only classify each roadway link and intersection node, but would associate the corresponding predicted crashes (by crash type) with each element. The disaggregate approach requires implementation of a "look-up" process similar to ones often employed in emissions analysis. Although more complex, a disaggregate approach would facilitate safety analysis at a corridor level, and may be useful for prioritizing specific road segments, intersections, or corridors for safety improvements. Further investigation of this approach is recommended.

ii) Crash Data Needs
LCOG's regional model networks contained elements for which there were no crash rates. As noted previously, there were no crash rates specific to freeway entrance and exit ramps, 1-way streets, or 3-lane road segments with continuous left-turn, a common configuration in the Eugene-Springfield area. Furthermore, for some road and intersection types, we found some volume classes for which there were no rates. In most instances, we assumed crash rates from adjacent cells for which there were observed data. As interest in crash prediction models increases, the body of research will no-doubt produce data sets with sufficient observations to compile crash rates for the missing road types and volume bins.

iii) Use of Continuous Functions
LCOG's tests using the continuous crash functions resulted in estimated base-year crashes comparable to those derived from the crash rate tables, but fewer predicted future-year crashes. The functions also resulted in a narrower range of predicted future crashes among the plan scenarios, and thus appear to be less sensitive to differences between scenarios. Since there are relatively fewer differences in the transportation networks than in their VMT by facility type, it is reasonable to conclude that the continuous functions we tested are less sensitive to differences in exposure than the crash rates.

iv) Other Approaches to Intersection Analysis
LCOG's regional model networks contain some information about intersection configurations, such as number of approach lanes and number of signal phases. In the modeling, these are only inputs to the approach capacity calculations. However, they may also be significant crash rate variables. Future research should investigate other ways to classify intersections for crash rate analysis.

Another related issue is whether all intersection crashes should be treated separately from the segment crashes. An alternative would be to model only the major intersections that are represented in the travel modeling network. In this case, the crashes at minor intersections would be combined with segment crashes.

Crash Forecasting Spreadsheet Observations
Applying a given set of rates to model output is a fairly straightforward exercise. Spreadsheets, widely available, are well suited to this task. Rates and forecasts for different system types (segment, intersection), highway or intersection types, volume levels, and plan scenarios can easily be managed and summarized in spreadsheet form.

However, several methodological issues were encountered in the development of the crash forecasting spreadsheets:

- The Need To Extend The Rate Tables
- The Transferability Of The Rates
- Interpretation of Results
- Use of System-Level Aggregations of Crash Forecasts

i) *The Need To Extend The Rate Tables*
As noted above, the rate tables developed in Knoxville needed to be extended to cover the highway classification volume distributions of the Eugene-Springfield area. Obviously, this will not be a problem when local data is used to develop rates for the Eugene-Springfield area. This illustrates the one of the problems associated with using rates from other areas and also indicates why aggregation of rates from different areas is difficult.

ii*) The Transferability Of The Rates*
It was anticipated prior to this application that there might be problems with using data from a different urban area. While it might be theorized that rates from a nearby urban area might be similar, it wasn't expected that the rates from Knoxville would necessarily be representative of rates in Eugene-Springfield. Again, while no technical comparison was completed, the aggregate rates for all the scenarios appear to be higher than what was expected based on local understanding of accident levels. Like the rate extension issue, this will not be a problem when local data is used.

iii*) Interpretation of Results*
The future year forecasts varied between a low of 22.35 average weekday crashes (2015 TPR Compliance) and a high of 24.98 (2015 Base Case). This difference of 2.63 crashes, or 12 percent may not be statistically significant. Future applications should provide analysts with some measure of the statistical significance of the difference. It should be noted that this is not just an issue for crash forecasts, but some of the inputs as well (VMT, etc.). A related issue is whether "average weekday crashes" represents a measure that will be meaningful to the public and policy makers. In all likelihood, these same public and policy makers are not any more comfortable with applying a dollar value to the crash forecasts, though that would provide a more relevant measuring stick.

Annualizing the results can make them more meaningful to policy makers and the public. However, the issue of statistical significance remains and is particularly important in helping discern the differences among alternative scenarios. In addition, a true annual result would need to include an estimate of weekend crashes, which was not done for this analysis.

iv) Interpretation of Aggregate and Disaggregate Results
Because the inputs to the forecast are VMT-based, the results of the analysis parallel the results using just total VMT as a measure. In other words, you would get the same ranking of the scenarios if you used VMT, or VMT/capita. While this is understandable, it raises the question of the value of developing an aggregate system measure.

The Eugene-Springfield MPO is moving toward the view that there is good congestion and bad congestion. In an area where the region is achieving desired land use patterns, it might tolerate higher levels of congestion, focusing instead on resolving congestion issues outside of those areas. If this is so, it is more useful to be able to conduct a more disaggregated analysis (e.g., at a corridor or intersection level). This would allow an analysis of where we should be focusing safety investments, using the network modeling as more of a screening tool.

v) Bike and Pedestrian Crash Data

These results are also limited by the lack of data on bike and pedestrian accidents. While the crash data used for the rates and models represent all types of crashes, bike and pedestrian crashes were not identified. Analysis of the impacts of alternative scenarios on the safety of bicyclists and pedestrians is very important to local policy makers, particularly in being able to understand the safety differences for various levels of investment in alternative modes. Disaggregating crash data to facilitate this kind of analysis would add considerable value to the overall results.

CONCLUSIONS AND RECOMMENDATIONS

This research analyzed crash data for a few selected urban areas from two states – North Carolina and Tennessee. It organized and analyzed the data in two different ways – all crashes assigned to individual road segments, and crashes separated in two groups of intersection and non-intersection crashes respectively. These analyses led to a few important findings and also unveiled a few important issues, which should be addressed in future research. These findings and related recommendations are presented below:

1. The separation of intersection crashes from others crashes for developing separate rates and/or regression models is recommended. This is a sound idea not only from conceptual considerations, but also for getting good correlation of crash rates, or number of crashes, with explanatory variables. It should be noted that freeways do not have intersections, and it may be difficult to separate interchange related crashes from others. The procedures used for identifying intersection and interchange related crashes in the crash data file should be examined carefully and improved, if necessary.
2. The results of this research indicate that crash rates for both non-intersection and intersection crashes do not always increase with an increase of traffic volume. The variation of crash rates with traffic volume may be different for different types of crashes. For example, with increasing volume on freeways crash rates for 'fatal and injury' crashes may decline while that for 'property damage only' crashes may increase. Similar patterns may be true for intersections also. These variations should be examined with more data.
3. It is known among traffic safety analysts that it is difficult to develop sound models for fatal crashes. This research also encountered difficulty with developing fatal crash models. The authors believe that combining fatal crash with injury crashes should be appropriate for developing crash prediction rates and models for planning level applications.
4. Future research should further examine alternative strategies for classifying roadway segments and intersections based on geometric and traffic control devices. What can be done, of course, depends on the information coded in the roadway inventory data file. Further, the ability of transportation planners to forecast the detailed characteristics associated with alternative highway networks for the future is an important consideration also. For example, with regard to safety there may be a difference between intersections with left turn lanes and those without such lanes. However, whether this information will be known for future networks is not clear. Further, providing left turn lanes at intersections may not be a long-range planning strategy.
5. Ideally each urbanized area should have crash prediction rates or models developed for itself with its own crash data. Further, the strategy for developing these rates or models should be coordinated with the procedures used for coding the highway network for travel forecasting models. These networks usually do not include all roads and intersections. Many minor intersections are not included on the network used for travel modeling. Therefore, for the sake of compatibility, a case can be made for including the crashes at minor intersections in the group of segment crashes, and for treating only those occurring at major intersections separately.
6. Developing crash prediction tools for long-range transportation planning deserves more attention and research. Although some of the detailed data needed for developing very

reliable models may not be available for long-range alternatives and thus cannot be used in the models, it appears that even without such detailed data reasonably reliable crash prediction models can be developed for planning level applications. Transportation planners and traffic safety analysts should work together to improve crash prediction methodologies. Good communication between these two groups is essential for making further improvements.

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TABLE 1. Injury Crash Rates for Road Segments Included in Micro-BENCOST

Number of Lanes	Access Control	ADT Ranges				
		8,000-15,999	16,000-23,999	24,000-35,999	36.000-57,999	58,000-75,999
4	Full	22.1	22.1	25.2	37.8	37.8
4	Partial	126.0	138.6	138.6	138.6	138.6
4	None	237.3	237.3	217.8	217.8	217.8

Notes:
1. Rate = Number of injury crashes per 100 million vehicle miles traveled.
2. Rates are for urban areas and these do not include crashes at intersections, railroad crossings and bridges.

TABLE 2. Segment Crash Rates

a) Segment Fatal + Injury Crash Rates (per Million VMT)

Highway	Two Lane	Multi-Lane Undivided	Two-Way Left Turn	Divided	Freeway	Freeway
Volume \ Number of Lanes	2	4	4	4	4	>4
0-	2.71					
2000-	2.14					
4000-	1.52	1.39				
8000-	1.25	1.56	1.45	1.72		
16000-	0.98	1.28	1.35	1.17		
24000-	1.07	1.48	1.53	1.34		
36000-		0.70	1.57	1.34	0.55	
58000-				0.51	0.42	0.43
>=					0.46	0.49

b) Segment Property Damage Only Crash Rates (per Million VMT)

Highway	Two Lane	Multi-Lane Undivided	Two-Way Left Turn	Divided	Freeway	Freeway
Volume \ Number of Lanes	2	4	4	4	4	>4
0-	4.50					
2000-	4.34					
4000-	3.38	4.02				
8000-	2.85	3.40	3.11	3.81		
16000-	2.48	2.50	2.49	2.39		
24000-	2.50	3.45	3.28	2.80		
36000-		1.49	3.32	2.51	1.45	
58000-				0.97	1.09	1.03
>=					0.96	1.08

TABLE 3. Intersection Crash Rates

a) Intersection Fatal + Injury Crash Rates (per Million entering vehicles)

Highway Type	Two Lane Signalized	Two Lane Full Stop	Two Lane Other	Undivided Signalized	Undivided Other	Two-Way Left Turn Signalized	Two-Way Left Turn Other	Divided Signalized	Divided Other
Volume Bins									
0-1999			0.454						
2000-3999			0.293		0.156				0.464
4000-7999	0.384	0.261	0.157		0.147				0.170
8000-15999	0.362	0.193	0.119	0.257	0.110		0.125		0.161
16000-23999	0.197	0.120	0.087	0.253	0.097	0.258	0.086	0.342	0.096
24000-35999	0.136		0.079	0.228	0.084	0.204	0.071	0.292	0.076
36000-57999	0.058		0.054	0.176	0.081	0.236	0.074	0.206	0.086
58000-75999						0.228			0.052
>=76000									0.011

b) Intersection Property Damage Only Crash Rates (per Million entering vehicles)

Highway Type	Two Lane Signalized	Two Lane Full Stop	Two Lane Other	Undivided Signalized	Undivided Other	Two-Way Left Turn Signalized	Two-Way Left Turn Other	Divided Signalized	Divided Other
Volume Bins									
0-1999			0.836						
2000-3999			0.435		0.449				0.723
4000-7999	1.037	0.536	0.324		0.289				0.473
8000-15999	0.691	0.394	0.255	0.629	0.213		0.258		0.297
16000-23999	0.418	0.313	0.177	0.691	0.176	0.486	0.166	0.813	0.214
24000-35999	0.300		0.188	0.573	0.178	0.414	0.139	0.608	0.154
36000-57999	0.124		0.120	0.395	0.182	0.533	0.156	0.503	0.183
58000-75999						0.471			0.123
>=76000									0.033

TABLE 4. Regression Models for Segment Crashes

HWY_TYPE/VARIABLE	R^2	R^2_{press}	MODEL	FORECAST
Freeway (n=145)				
Total-accidents	.4880	.4662	Ln(tot+1)=2.547329+.0137348*aadt2+.654683*seg-leng	19.33
Inj.+fatal-accidents	.4608	.4390	Ln(inj+fat+1)=1.516071+.0126802*aadt2+ .632381*seg-leng	6.09
Non-inj.-accidents	.4819	.4594	Ln(noninj+1)=2.143333+.0140935*aadt2+ .653778*seg-leng	12.61
Undivided ((n=237)				
Total-accidents	.3113	.2952	Ln(tot+1)=1.843907+.031553*aadt2+1.563333*seg-leng	17.9
Inj.+fatal-accidents	.3653	.3509	Ln(inj+fat+1)=.804274+.0296066*aadt2+ 1.69170*seg-leng	6.00
Non-inj.-accidents	.2738	.2567	Ln(noninj+1)=1.56665+.030128*aadt2+ 1.381664*seg-leng	11.92
Divided (n=251)				
Total-accidents	.2752	.2582	Ln(tot+1)=2.045214+.0253678*aadt2+.974015*seg-leng	15.21
Inj.+fatal-accidents	.3011	.2839	Ln(inj+fat+1)=1.091859+.0232253*aadt2+ 1.003870*seg-leng	5.21
Non-inj.-accidents	.2389	.2201	Ln(noninj+1)=1.685403+.0262748*aadt2+ .794659*seg-leng	9.44
Left turn (n=296)				
Total-accidents	.3403	.3286	Ln(tot+1)=1.80802+.0410928*aadt2+1.231951*seg-leng	16.03
Inj.+fatal-accidents	.3568	.3423	Ln(inj+fat+1)=.863522+.0374986*aadt2+1.286914*seg-leng	5.57
Non-inj.-accidents	.3048	.2879	Ln(noninj+1)=1.463296+.0401585*aadt2+ 1.141019*seg-leng	10.42
Two lane (n=602)				
Total-accidents	.2851	.2765	Ln(tot+1)=1.742611+.0451726*aadt2+.700194*seg-leng	11.74
Inj.+fatal-accidents	.3153	.3071	Ln(inj+fat+1)=.838447+.0375806*aadt2+.686309*seg-leng	3.75
Non-inj.-accidents	.2662	.2574	Ln(noninj+1)=1.449472+.0438423*aadt2+ .644050*seg-leng	8.11

TABLE 5. Classification Codes used to Organize Model Output

Link Type 10's Digit = Functional Class	
1	Freeway, 6-lane
2	Freeway, 4-lane
3	Divided, 4-lane (Also used for 1-way couplet classification
4	5-Lane Continuous L.T. (also used for 3-lane)
5	Undivided, 4-lane
6	Undivided, 2-lane
Link Type 1's Digit = Volume Class	
1	0-1999
2	2000-3999
3	4000-7999
4	8000-15999
5	16000-23999
6	24000-35999
7	36000-57999
8	58000-75999
9	>=76000

Intersection Type 100's Digit (ityp) = Functional Class, Highest Classification of entering links (i.e, lowest linktype)	
1	Freeway, 6-lane
2	Freeway, 4-lane
3	Divided, 4-lane (Also used for 1-way couplet classification
4	5-Lane Continuous L.T. (also used for 3-lane)
5	Undivided, 4-lane
6	Undivided, 2-lane

Intersection Type 10's Digit = Control Type	
2	Signal
3	All-Way Stop
4	Other

Entersection Type 1's Digit = Volume Class = total	
1	0-1999
2	2000-3999
3	4000-7999
4	8000-15999
5	16000-23999
6	24000-35999
7	36000-57999
8	58000-75999
9	>=76000

TABLE 6. Model data

EUGENE-SPRINGFIELD EMME/2 MODEL OUTPUT FOR CRASH ANALYSIS
12/10/2002

Index	Scen#	Scenario
1	**174**	**1995 Base Year**
2	**4784**	**2015 Base Case**
3	**5084**	**2015 Demand Management**
4	**5184**	**2015 TPR Compliance**
5	**5010**	**2015 Land Use Emphasis**
6	**5060**	**2015 Balanced Strategies**
7	**5110**	**2015 System Changes**

4		2015 TPR Compliance	1995 Base Year	2015 Base Case	2015 Demand Management	2015 TPR Compliance	2015 Land Use Emphasis	2015 Balanced Strategies	2015 System Changes
		Scenario	**174**	**4784**	**5084**	**5184**	**5010**	**5060**	**5110**
ms11:	crt11v	12/9/2002 Crash Rate Link Type 11 Weekday VMT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ms12:	crt12v	12/9/2002 Crash Rate Link Type 12 Weekday VMT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ms70:	crt70v	12/9/2002 Crash Rate Link Type 70 Weekday VMT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Total VMT	**3353088.1**	**5147897.6**	**4771263.0**	**4362607.1**	**4963440.1**	**4822615.5**	**5002948.1**
ms101	:iv321	12/9/2002 EntVol for ityp=3 / Cont_Vol Clas=21	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ms102	:iv322	12/9/2002 EntVol for ityp=3 / Cont_Vol Clas=22	5550.8	0.0	11253.1	11245.8	11678.8	3902.7	7216.6
ms215	:iv648	12/9/2002 EntVol for ityp=6 / Cont_Vol Clas=48	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ms216	:iv649	12/9/2002 EntVol for ityp=6 / Cont_Vol Clas=49	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		TOTAL VOL	**7940810.5**	**11868247**	**10754156.7**	**9973796.2**	**11079813.1**	**10964761.6**	**11127846.1**

TABLE 7. Formatted Model Output

Select Scenario

2015 TPR Compliance ▼

EMME/2 Model Output

Scenario: 2015 TPR Compliance

Weekday Link VMT

Hwy Type	Nbr_Lanes	0-1999	2000-3999	4000-7999	8000-15999	16000-23999	24000-35999	36000-57999	58000-75999	>= 76000
Two Lane	2	50,572	118,175	345,242	654,578	191,322	28,063	0	0	0
Undivided	4	570	6,240	22,611	123,955	188,469	72,146	9,064	0	0
Left Turn	4	65	2,551	7,510	103,703	161,046	260,144	25,419	0	0
Divided	4	682	1,795	4,939	72,204	109,492	126,809	148,144	67,258	12,280
Freeway	4	225	1,238	4,687	29,357	90,053	210,255	792,525	236,881	0
Freeway	> 4	0	0	0	0	0	0	2,971	79,370	0

VMT CHECK	4,362,610	OK

Note: Scenario VMT does not include locals or intrazonals

Weekday Intersection Entering Volumes

Hwy Type	Nbr_Lanes	0-1999	2000-3999	4000-7999	8000-15999	16000-23999	24000-35999	36000-57999	58000-75999	>= 76000
Two Lane	Signalized	0	0	21,280	318,616	252,567	168,449	0	0	0
Two Lane	Full Stop	0	10,365	71,920	222,754	35,217	0	0	0	0
Two Lane	Other	22,888	72,471	267,860	760,431	253,976	79,200	0	0	0
Undivided	Signalized	0	0	31,442	80,888	412,864	552,386	131,767	0	0
Undivided	Other	0	2,298	24,085	125,850	135,324	84,085	0	0	0
Left Turn	Signalized	0	0	14,295	169,817	368,804	1,010,130	453,892	0	0
Left Turn	Other	0	3,890	0	26,100	82,296	149,670	0	0	0
Divided	Signalized	0	11,246	21,873	272,313	883,131	1,023,706	843,773	0	0
Divided	Other	1,449	2,890	32,286	184,092	112,414	123,895	42,853	0	0

VOL CHECK	9,973,798	OK

Note: Scenario Entering Volume is for math check only

TABLE 8a. Extended Segment Crash Rates

Segment Fatal+ Injury Crash Rates (per Million VMT)						
Knoxville, TN 2000?						
	1	2	3	4	5	6
Hwy Type	Two Lane	Undivided	Left Turn	Divided	Freeway	Freeway
Nbr_Lanes	2	4	4	4	4	> 4
Volume Bins						
0-1999	2.710	1.392	1.457	1.728	0.553	
2000-3999	2.144	1.392	1.457	1.728	0.553	
4000-7999	1.526	1.392	1.457	1.728	0.553	
8000-15999	1.251	1.569	1.457	1.728	0.553	0.439
16000-23999	0.987	1.281	1.358	1.177	0.553	0.439
24000-35999	1.073	1.481	1.539	1.342	0.553	0.439
36000-57999	1.073	0.701	1.579	1.340	0.553	0.439
58000-75999				0.515	0.421	0.439
>= 76000				0.515	0.463	0.496
Segment Property Damage Only Crash Rates (per Million VMT)						
Knoxville, TN 2000?						
Hwy Type	Two Lane	Undivided	Left Turn	Divided	Freeway	Freeway
Nbr_Lanes	2	4	4	4	4	> 4
Volume Bins						
0-1999	4.508	4.025	3.112	3.814	1.459	
2000-3999	4.348	4.025	3.112	3.814	1.459	
4000-7999	3.382	4.025	3.112	3.814	1.459	
8000-15999	2.852	3.409	3.112	3.814	1.459	1.033
16000-23999	2.481	2.504	2.491	2.399	1.459	1.033
24000-35999	2.509	3.451	3.280	2.803	1.459	1.033
36000-57999	2.509	1.494	3.326	2.513	1.459	1.033
58000-75999				0.977	1.091	1.033
>= 76000				0.977	0.960	1.081

TABLE 8b. Extended Intersection Crash Rates

Intersection Fatal+ Injury Crash Rates (per Million entering vehicles)
Knoxville, TN 2000?

Hwy Type Nbr_Lanes	Two Lane Signalized	Two Lane Full Stop	Two Lane Other	Undivided Signalized	Undivided Other	Left Turn Signalized	Left Turn Other	Divided Signalized	Divided Other
Volume Bins									
0-1999	0.384	0.261	0.454	0.257	0.156	0.258	0.125	0.342	
2000-3999	0.384	0.261	0.293	0.257	0.156	0.258	0.125	0.342	0.464
4000-7999	0.384	0.261	0.157	0.257	0.147	0.258	0.125	0.342	0.170
8000-15999	0.362	0.193	0.119	0.257	0.110	0.258	0.125	0.342	0.161
16000-23999	0.197	0.120	0.087	0.253	0.097	0.258	0.086	0.342	0.096
24000-35999	0.136	0.120	0.079	0.228	0.084	0.204	0.071	0.292	0.076
36000-57999	0.058	0.120	0.054	0.176	0.081	0.236	0.074	0.206	0.086
58000-75999						0.228			0.052
>= 76000									0.011

Intersection Property Damage Only Crash Rates(per Million entering vehicles)
Knoxville, TN 2000?

Hwy Type Nbr_Lanes	Two Lane Signalized	Two Lane Full Stop	Two Lane Other	Undivided Signalized	Undivided Other	Left Turn Signalized	Left Turn Other	Divided Signalized	Divided Other
Volume Bins									
0-1999	1.037	0.536	0.836	0.629	0.449	0.486	0.258	0.813	
2000-3999	1.037	0.536	0.435	0.629	0.449	0.486	0.258	0.813	0.723
4000-7999	1.037	0.536	0.324	0.629	0.289	0.486	0.258	0.813	0.473
8000-15999	0.691	0.394	0.255	0.629	0.213	0.486	0.258	0.813	0.297
16000-23999	0.418	0.313	0.177	0.691	0.176	0.486	0.166	0.813	0.214
24000-35999	0.300	0.313	0.188	0.573	0.178	0.414	0.139	0.608	0.154
36000-57999	0.124	0.313	0.120	0.395	0.182	0.533	0.156	0.503	0.183
58000-75999						0.471			0.123
>= 76000									0.033

TABLE 9. Example Scenario Crash Forecast Spreadsheet

2015 TDM Scenario Average Weekday										
Intersection Fatal+ Injury Crash Rates (per Million entering vehicles)										
Intersection #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Intersection Type	**Two Lane**	**Two Lane**	**Two Lane**	**Undivided**	**Undivided**	**Left Turn**	**Left Turn**	**Divided**	**Divided**	
Treatment	**Signalized**	**Full Stop**	**Other**	**Signalized**	**Other**	**Signalized**	**Other**	**Signalized**	**Other**	**Total**
Volume Bins										
0-1999	0.0000	0.0000	0.0079	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0079
2000-3999	0.0000	0.0008	0.0196	0.0000	0.0004	0.0000	0.0004	0.0038	0.0000	0.0251
4000-7999	0.0055	0.0153	0.0423	0.0079	0.0045	0.0041	0.0000	0.0098	0.0054	0.0948
8000-15999	0.0846	0.0398	0.0947	0.0093	0.0092	0.0324	0.0020	0.0468	0.0231	0.3420
16000-23999	0.0708	0.0140	0.0244	0.1153	0.0162	0.0898	0.0070	0.2747	0.0158	0.6279
24000-35999	0.0224	0.0000	0.0106	0.1298	0.0099	0.1745	0.0129	0.3669	0.0070	0.7339
36000-57999	0.0025	0.0000	0.0000	0.0296	0.0000	0.1966	0.0000	0.1971	0.0106	0.4364
58000-75999	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
>= 76000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.1858	0.0700	0.1995	0.2920	0.0401	0.4973	0.0223	0.8991	0.0619	2.2680

TABLE 10. Scenario Comparison Summary Sheet

TransPlan Alternative Plan Scenario Comparison							
Crash Estimate Summary							
Average Weekday Crashes							
Segment Totals	**Base Year**	**2015 Base Case**	**2015 TDM Emphasis**	**2015 Land Use Emphasis**	**2015 System Change Emphasis**	**2015 Balanced Strategies**	**2015 TPR Compliance**
Fatal+Injury	**3.88**	**5.45**	5.13	**5.32**	**5.36**	**5.23**	**4.67**
Property Damage Only	**8.48**	**12.10**	11.40	**11.76**	**11.87**	**11.54**	**10.65**
Total	**12.35**	**17.55**	**16.52**	**17.08**	**17.23**	**16.77**	**15.32**
Intersection Totals	**Base Year**	**2015 Base Case**	**2015 TDM Emphasis**	**2015 Land Use Emphasis**	**2015 System Change Emphasis**	**2015 Balanced Strategies**	**2015 TPR Compliance**
Fatal+Injury	**1.81**	**2.33**	**2.27**	**2.32**	**2.32**	**2.30**	**2.19**
Property Damage Only	**3.97**	**5.11**	**5.02**	**5.09**	**5.08**	**5.04**	**4.84**
Total	**5.78**	**7.43**	**7.29**	**7.41**	**7.40**	**7.33**	**7.03**
System Totals	**Base Year**	**2015 Base Case**	**2015 TDM Emphasis**	**2015 Land Use Emphasis**	**2015 System Change Emphasis**	**2015 Balanced Strategies**	**2015 TPR Compliance**
Fatal+Injury	**5.68**	**7.77**	**7.39**	**7.64**	**7.68**	**7.53**	**6.86**
Property Damage Only	**12.45**	**17.21**	**16.42**	**16.85**	**16.95**	**16.58**	**15.49**
Total	**18.14**	**24.98**	**23.81**	**24.50**	**24.63**	**24.11**	**22.35**

TABLE 11. Scenario Comparison Summary by Facility Type

Comparisons By Facility Type

Intersection Comparisons

Average Weekday Intersection Crashes

Fatal+ Injury			1995 Base Year	2015 Base Case	2015 TDM	2015 Land Use	2015 System Changes	2015 Balanced Strategies	2015 TPR Compliance
	Intersection Type	Treatment	Total	Total	Total	Total	Total	Total	Total
	Two Lane	Signalized	0.17	0.19	0.19	0.17	0.17	0.17	0.20
	Two Lane	Full Stop	0.06	0.08	0.07	0.07	0.07	0.07	0.07
	Two Lane	Other	0.18	0.21	0.20	0.20	0.20	0.20	0.19
	Undivided	Signalized	0.24	0.32	0.29	0.28	0.28	0.28	0.28
	Undivided	Other	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	Left Turn	Signalized	0.36	0.54	0.50	0.53	0.53	0.52	0.46
	Left Turn	Other	0.03	0.02	0.02	0.03	0.03	0.03	0.02
	Divided	Signalized	0.70	0.86	0.90	0.93	0.92	0.92	0.88
	Divided	Other	0.03	0.07	0.06	0.07	0.07	0.08	0.06
		Total	**1.81**	**2.33**	**2.27**	**2.32**	**2.32**	**2.30**	**2.19**

Property Damage Only			1995 Base Year	2015 Base Case	2015 TDM	2015 Land Use	2015 System Changes	2015 Balanced Strategies	2015 TPR Compliance
	Intersection Type	Treatment	Total	Total	Total	Total	Total	Total	Total
	Two Lane	Signalized	0.35	0.39	0.38	0.36	0.36	0.35	0.40
	Two Lane	Full Stop	0.13	0.16	0.15	0.15	0.15	0.15	0.14
	Two Lane	Other	0.34	0.43	0.41	0.40	0.41	0.40	0.39
	Undivided	Signalized	0.61	0.80	0.75	0.72	0.71	0.70	0.72
	Undivided	Other	0.09	0.08	0.08	0.07	0.07	0.07	0.07
	Left Turn	Signalized	0.72	1.12	1.04	1.10	1.11	1.08	0.93
	Left Turn	Other	0.05	0.05	0.04	0.05	0.05	0.05	0.04
	Divided	Signalized	1.62	1.93	2.04	2.09	2.07	2.09	2.01
	Divided	Other	0.06	0.15	0.13	0.15	0.15	0.15	0.12
		Total	**3.97**	**5.11**	**5.02**	**5.09**	**5.08**	**5.04**	**4.84**

Intersection Total			1995 Base Year	2015 Base Case	2015 TDM	2015 Land Use	2015 System Changes	2015 Balanced Strategies	2015 TPR Compliance
	Intersection Type	Treatment	Total	Total	Total	Total	Total	Total	Total
	Two Lane	Signalized	0.52	0.57	0.57	0.53	0.53	0.52	0.59
	Two Lane	Full Stop	0.20	0.24	0.22	0.22	0.22	0.21	0.21
	Two Lane	Other	0.51	0.63	0.61	0.60	0.61	0.60	0.58
	Undivided	Signalized	0.85	1.12	1.04	1.00	0.99	0.98	1.01
	Undivided	Other	0.13	0.13	0.12	0.11	0.11	0.10	0.11
	Left Turn	Signalized	1.08	1.66	1.53	1.63	1.64	1.60	1.38
	Left Turn	Other	0.08	0.07	0.07	0.08	0.08	0.08	0.06
	Divided	Signalized	2.33	2.79	2.94	3.02	2.99	3.01	2.89
	Divided	Other	0.09	0.22	0.19	0.22	0.22	0.23	0.18
		Total	**5.78**	**7.43**	**7.29**	**7.41**	**7.40**	**7.33**	**7.03**

TABLE 11. Scenario Comparison Summary by Facility Type (cont.)

Road Segment Comparisons									
Average Weekday Road Segment Crashes									
Fatal+ Injury			1995 Base Year	2015 Base Case	2015 TDM	2015 Land Use	2015 System Changes	2015 Balanced Strategies	2015 TPR Compliance
	Segment Type	Nbr_Lanes	Total	Total	Total	Total	Total	Total	Total
	Two Lane	2	1.62	2.18	2.07	2.03	2.06	1.99	1.95
	Undivided	4	0.49	0.66	0.63	0.65	0.66	0.67	0.59
	Left Turn	4	0.66	1.00	0.91	0.99	0.99	0.96	0.82
	Divided	4	0.52	0.75	0.72	0.82	0.82	0.81	0.68
	Freeway	4	0.56	0.81	0.76	0.73	0.73	0.70	0.72
	Freeway	> 4	0.03	0.04	0.04	0.10	0.10	0.10	0.04
		Total	**3.88**	**5.45**	**5.13**	**5.32**	**5.36**	**5.23**	**4.67**
Property Damage Only			1995 Base Year	2015 Base Case	2015 TDM	2015 Land Use	2015 System Changes	2015 Balanced Strategies	2015 TPR Compliance
	Segment Type	Nbr_Lanes	Total	Total	Total	Total	Total	Total	Total
	Two Lane	2	3.49	4.90	4.62	4.53	4.60	4.41	4.32
	Undivided	4	1.08	1.42	1.36	1.39	1.40	1.43	1.28
	Left Turn	4	1.33	2.08	1.89	2.04	2.04	1.97	1.69
	Divided	4	1.04	1.52	1.45	1.66	1.66	1.65	1.37
	Freeway	4	1.47	2.09	1.99	1.91	1.92	1.85	1.90
	Freeway	> 4	0.06	0.10	0.09	0.24	0.23	0.23	0.09
		Total	**8.48**	**12.10**	**11.40**	**11.76**	**11.87**	**11.54**	**10.65**
Road Segment Total			1995 Base Year	2015 Base Case	2015 TDM	2015 Land Use	2015 System Changes	2015 Balanced Strategies	2015 TPR Compliance
	Segment Type	Nbr_Lanes	Total	Total	Total	Total	Total	Total	Total
	Two Lane	2	5.12	7.08	6.69	6.56	6.66	6.40	6.28
	Undivided	4	1.57	2.08	1.98	2.04	2.06	2.10	1.87
	Left Turn	4	2.00	3.07	2.81	3.02	3.03	2.93	2.52
	Divided	4	1.55	2.27	2.16	2.49	2.49	2.46	2.05
	Freeway	4	2.03	2.90	2.75	2.63	2.65	2.56	2.63
	Freeway	> 4	0.09	0.14	0.13	0.34	0.34	0.33	0.12
		Total	**12.35**	**17.55**	**16.52**	**17.08**	**17.23**	**16.77**	**15.32**

TABLE 12. Scenario Comparison Summary – Annualized Results

TransPlan Alternative Plan Scenario Comparison							
Crash Estimate Summary							
Average Annual Crashes							
Annualization Factor:	261						
Segment Totals	**Base Year**	**2015 Base Case**	**2015 TDM Emphasis**	**2015 Land Use Emphasis**	**2015 System Change Emphasis**	**2015 Balanced Strategies**	**2015 TPR Compliance**
Fatal+Injury	1,012	1,421	1,338	1,390	1,400	1,366	1,218
Property Damage Only	2,213	3,158	2,975	3,070	3,097	3,012	2,780
Total	3,225	4,580	4,313	4,459	4,497	4,378	3,998
Intersection Totals	**Base Year**	**2015 Base Case**	**2015 TDM Emphasis**	**2015 Land Use Emphasis**	**2015 System Change Emphasis**	**2015 Balanced Strategies**	**2015 TPR Compliance**
Fatal+Injury	471	607	592	605	605	599	573
Property Damage Only	1,037	1,333	1,310	1,329	1,326	1,315	1,263
Total	1,509	1,940	1,902	1,934	1,931	1,914	1,835
System Totals	**Base Year**	**2015 Base Case**	**2015 TDM Emphasis**	**2015 Land Use Emphasis**	**2015 System Change Emphasis**	**2015 Balanced Strategies**	**2015 TPR Compliance**
Fatal+Injury	1,483	2,028	1,930	1,995	2,005	1,965	1,791
Property Damage Only	3,250	4,492	4,285	4,399	4,424	4,326	4,043
Total	4,733	6,520	6,215	6,394	6,428	6,292	5,834

TABLE 13a. Continuous Function Test Results

Predicted Annual Non-Intersection Crashes

Using University of Tennessee Road Segment Crash Functions

	Scenario 174	4784	5010	5060	5084	5160	5184
Type	1995 Base	2015 Base Case	2015 Land Use Emphasis	2015 Balanced Strategies	2015 Demand Management Emphasis	2015 System Changes Emphasis	2015 TPR Compliance
Freeway	606	680	690	683	666	691	648
Undivided	476	523	523	521	507	523	500
Divided	431	671	693	691	639	691	612
Left Turn	452	567	601	597	542	602	519
Two-Lane	1,953	2,076	2,048	2,041	2,044	2,055	2,015
total	3,918	4,517	4,555	4,533	4,398	4,562	4,294

TABLE 13b. Comparison of Continuous Functions and Crash Rate Table Results

Predicted Daily Crashes on Road Segments

Comparison of Continuous Functions with Crash-Rate Based Results
(annualization factor = 312)

	Base Year	2015 Base Case	2015 TDM Emphasis	2015 Land Use Emphasis	2015 System Change Emphasis	2015 Balanced Strategies	2015 TPR Compliance
Using Crash Rates	12.35	17.55	16.52	17.08	17.23	16.77	15.32
Using Continuous Functions	12.56	14.48	14.10	14.60	14.62	14.53	13.76

Comparison by Facility Type - Example

(Using 2015 Base Case)

	Rate-Based	Continuous Function
Freeway	3.04	2.18
Undivided	2.08	1.68
Divided	2.27	2.15
Left Turn	3.07	1.82
Two-Lane	7.08	6.65
total	17.55	14.48

FIGURE 1. Segment (Non-Intersection) Crash Rates

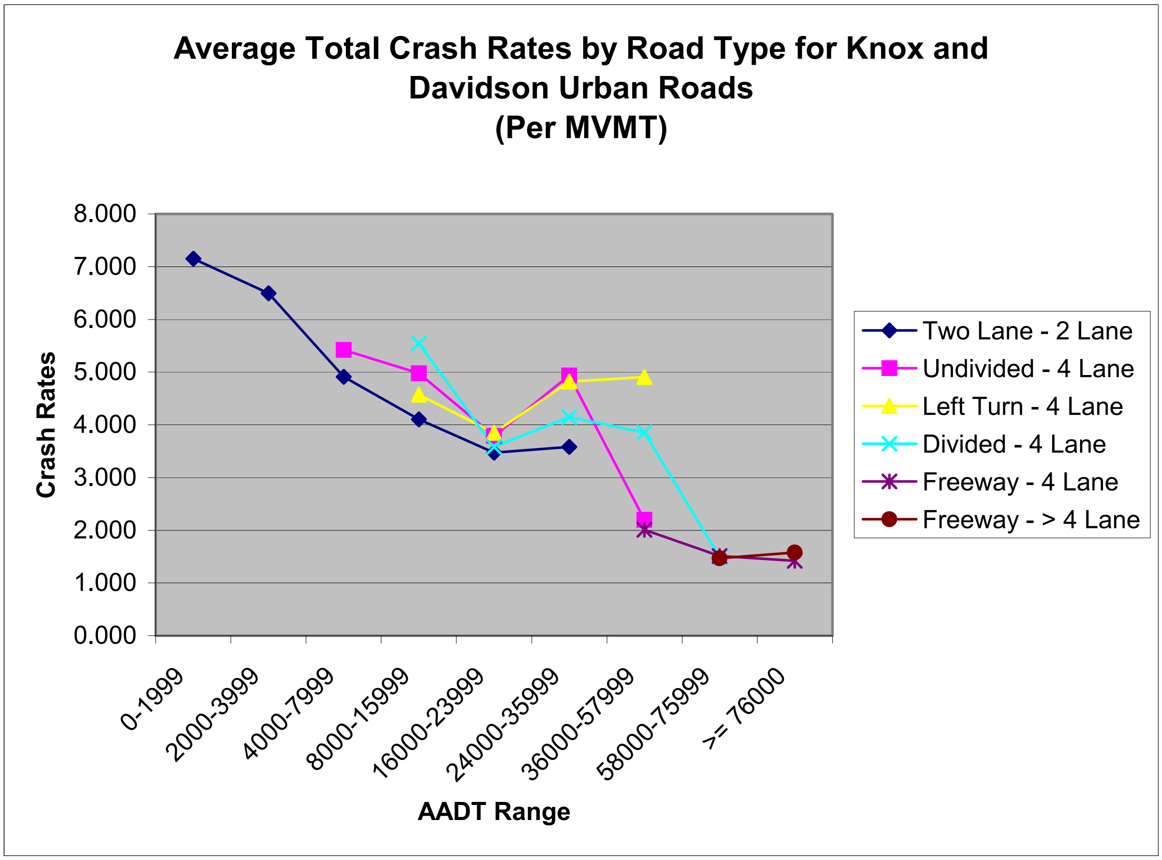

FIGURE 2. Intersection Crash rates

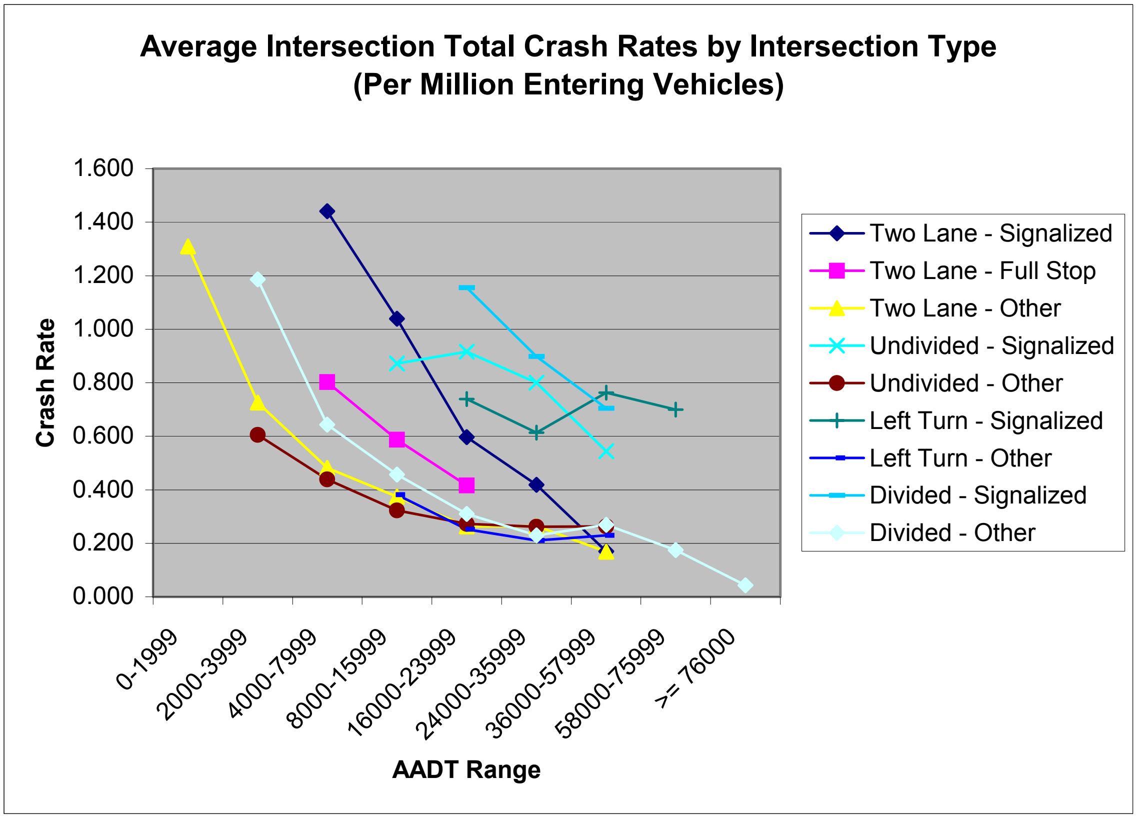

FIGURE 3. Plot of Model Generated Values of Crashes for Segment Length of 1.0 mile

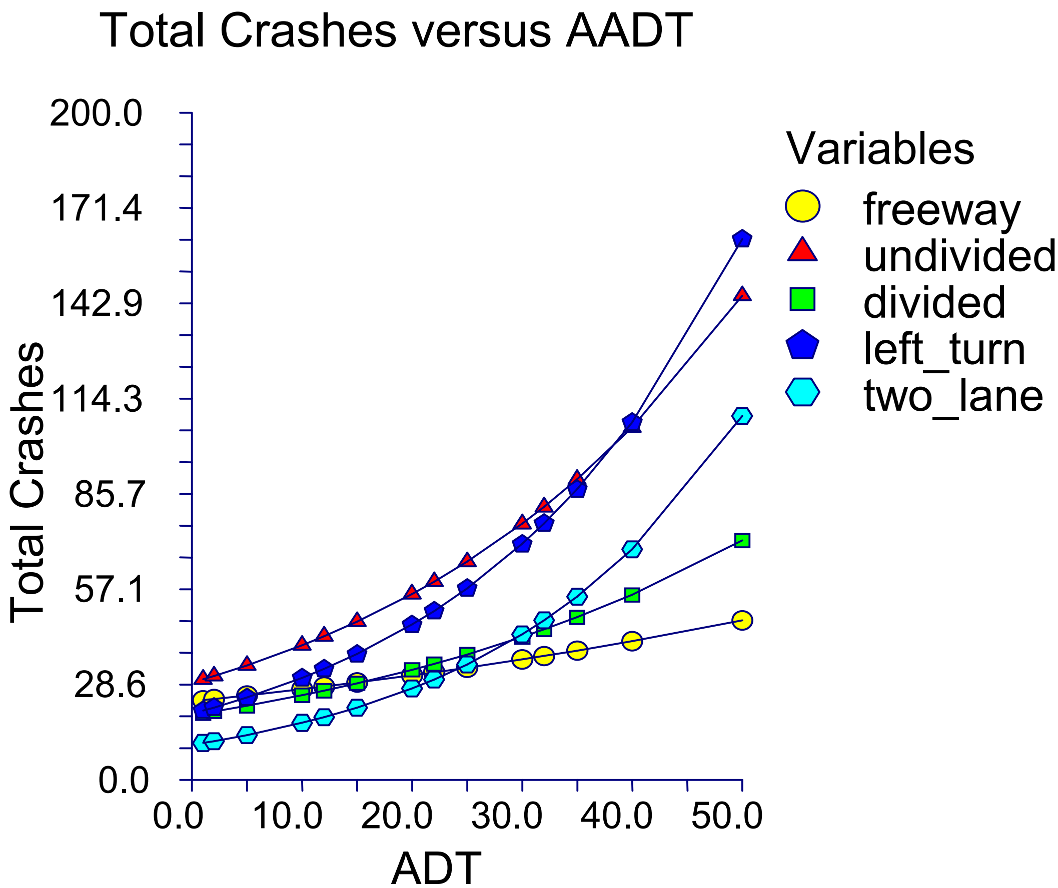

FIGURE 4. Segment Crash Rates Based on Regression Models