

# KENTUCKY TRANSPORTATION CENTER

*College of Engineering*

**SAFETY AND CAPACITY EVALUATION FOR  
INTERSTATES IN KENTUCKY**





**UNIVERSITY OF KENTUCKY**

**College of Engineering**  
**Kentucky Transportation Center**

***Our Mission***

We provide services to the transportation community through research, technology transfer and education. We create and participate in partnerships to promote safe and effective transportation systems.

***We Value...***

Teamwork -- Listening and Communicating, Along with Courtesy and Respect for Others  
Honesty and Ethical Behavior  
Delivering the Highest Quality Products and Services  
Continuous Improvement in All That We Do

*For more information or a complete publication list, contact us*

**KENTUCKY TRANSPORTATION CENTER**

176 Raymond Building  
University of Kentucky  
Lexington, Kentucky 40506-0281

(859) 257-4513  
(859) 257-1815 (FAX)  
1-800-432-0719  
[www.ktc.uky.edu](http://www.ktc.uky.edu)  
[ktc@engr.uky.edu](mailto:ktc@engr.uky.edu)

*The University of Kentucky is an Equal Opportunity Organization*

Research Report KTC-05-06/1F-56-04-1F

Safety and Capacity Evaluation for Interstates in Kentucky

by

Adam J. Kirk  
Jerry G. Pigman  
Kenneth R. Agent  
Barry House

Kentucky Transportation Center

College of Engineering  
University of Kentucky  
Lexington, Kentucky

in cooperation with

Kentucky Transportation Cabinet  
Commonwealth of Kentucky

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of policies of the University of Kentucky or the Kentucky Transportation Cabinet. This report does not constitute a standard, specification, or regulation. The inclusion of manufacturer names and trade names is for identification purposes and is not to be considered an endorsement.

April 2005

|  |  |   |                  |
|--|--|---|------------------|
| <b>1. Report Number</b><br>KTC-05-06/1F-56-04-1F   | <b>2. Government Accession No.</b>                             | <b>3. Recipient's Catalog No.</b>   |                  |
| <b>4. Title and Subtitle</b><br>Safety and Capacity Evaluation for Interstates in Kentucky   |  | <b>5. Report Date</b><br>April 2005   |                  |
|  |  | <b>6. Performing Organization Code</b>  |                  |
| <b>7. Author(s)</b><br>Adam Kirk, Jerry Pigman, Kenneth Agent, and Barry House   |  | <b>8. Performing Organization Report No.</b><br>KTC-05-06/1F-56-04-1F                                       |                  |
| <b>9. Performing Organization Name and Address</b><br>Kentucky Transportation Center<br>College of Engineering<br>University of Kentucky<br>Lexington, Kentucky 40506-0281   |  | <b>10. Work Unit No.</b>  |                  |
|  |  | <b>11. Contract or Grant No.</b><br>KYSPR-04-56   |                  |
| <b>12. Sponsoring Agency Name and Address</b><br>Kentucky Transportation Cabinet<br>State Office Building<br>Frankfort, Kentucky 40602   |  | <b>13. Type of Report and Period Covered</b><br>Final   |                  |
|  |  | <b>14. Sponsoring Agency Code</b>   |                  |
| <b>15. Supplementary Notes</b><br>Prepared in cooperation with the Kentucky Transportation Cabinet<br>and the Federal Highway Administration   |  |   |                  |
| <b>16. Abstract</b><br><br>This analysis and evaluation was directed toward assessing safety and capacity issues on interstates in Kentucky and, particularly, the manner in which commercial vehicle traffic affects these issues. Analyses was undertaken to show past trends and project future traffic. Previous research was relied upon to show the level of safety on each of the interstates relative to statewide averages. Analyses were performed to evaluate the impact on safety when comparing segments by number of lanes available for through traffic (4, 6, and 8-lane highway sections). Delay on the interstates was calculated based on closure times due to crashes and estimates were made of the relative impact if additional lanes were available. Volume versus capacity assessments were performed to show the operational level of each interstate. Insight and knowledge gained from other similar studies were considered and incorporated where appropriate. |  |   |                  |
| <b>17. Key Words</b><br><br>Safety<br>Capacity<br>Recurring Delay<br>Non-Recurring Delay   |  | <b>18. Distribution Statement</b><br><br>Unlimited, with approval of the Kentucky<br>Transportation Cabinet |                  |
| <b>19. Security Classification (report)</b><br>Unclassified  | <b>20. Security Classification (this page)</b><br>Unclassified | <b>21. No. of Pages</b><br>20   | <b>22. Price</b> |

## TABLE OF CONTENTS

|  |           |
|--|-----------|
| <b>EXECUTIVE SUMMARY .....</b>   | <b>V</b>  |
| <b>1. INTRODUCTION.....</b>  | <b>1</b>  |
| <b>2. SCOPE .....</b>  | <b>2</b>  |
| <b>3. EXISTING CONDITIONS .....</b>                                    | <b>3</b>  |
| 3.1 ROADWAY CHARACTERISTICS .....                                      | 3         |
| 3.2 HISTORICAL TRAFFIC GROWTH.....                                     | 6         |
| <b>4. PROCESSES AND PROCEDURES .....</b>                               | <b>10</b> |
| 4.1 FUTURE TRAFFIC PROJECTIONS .....                                   | 11        |
| 4.2 OPERATIONAL ANALYSIS.....  | 11        |
| 4.3 SAFETY ANALYSIS.....   | 15        |
| 4.4 ALTERNATIVE ANALYSIS .....   | 17        |
| <b>5. RESULTS .....</b>  | <b>18</b> |
| 5.1 INTERSTATE VOLUME PROJECTIONS .....                                | 18        |
| 5.2 OPERATIONAL ANALYSIS RESULTS .....                                 | 20        |
| 5.3 SAFETY ANALYSIS.....   | 30        |
| 5.4 ALTERNATIVE ANALYSIS.....  | 43        |
| 5.5 ADDITIONAL ANALYSIS.....   | 47        |
| <b>6. SUMMARY OF OTHER INTERSTATE SAFETY AND CAPACITY STUDIES.....</b> | <b>52</b> |
| <b>7. SUMMARY OF RESULTS AND CONCLUSIONS .....</b>                     | <b>54</b> |
| <b>8. REFERENCES.....</b>  | <b>56</b> |
| <b>9. APPENDIX A: HPMS SECTION DATA.....</b>                           | <b>58</b> |

## LIST OF FIGURES

|   |    |
|---|----|
| Figure 1: Study Roadway and Urban Boundary Map.....   | 5  |
| Figure 2: Interstate 24 Historical Traffic Growth.....                                      | 7  |
| Figure 3: Interstate 64 Historical Traffic Growth.....                                      | 7  |
| Figure 4: Interstate 65 Historical Traffic Growth.....                                      | 8  |
| Figure 5: Interstate 71 Historical Traffic Growth.....                                      | 8  |
| Figure 6: Interstate 75 Historical Traffic Growth.....                                      | 9  |
| Figure 7: Average Hourly Volume Distribution.....   | 12 |
| Figure 8: K Factor by Period .....  | 13 |
| Figure 9: Deterministic Queuing Model.....  | 14 |
| Figure 10: Miles of Roadway by LOS and Study Period (2003).....                             | 21 |
| Figure 11: Miles of Roadway by Peak Hour LOS and Rural/Urban Designation(2003) .....        | 21 |
| Figure 12: Miles of Roadway by LOS and Study Period (2030).....                             | 22 |
| Figure 13: Miles of Roadway by Peak Hour LOS and Rural/Urban Designation(2030) .....        | 22 |
| Figure 14: 2003 Peak Hour LOS Analysis .....  | 23 |
| Figure 15: 2030 Peak Hour LOS Analysis .....  | 24 |
| Figure 16: Incident Duration by Rural/Urban Classification) .....                           | 26 |
| Figure 17: Non-Recurring Delay by Period and Rural/Urban Classification (2003) .....        | 27 |
| Figure 18: Non-Recurring Delay by Period and Rural/Urban Classification (2030) .....        | 28 |
| Figure 19: Average Non-Recurring and Recurring Congestion (Urban and Rural Interstates) ... | 29 |
| Figure 20: CRF by Section (All Crashes).....  | 36 |
| Figure 21: CRF by Section (Commercial Vehicle Crashes).....                                 | 37 |
| Figure 22: Effect of ADT on Crash Rate.....   | 42 |
| Figure 23: Effect of Interchange Density on Crash Rate.....                                 | 43 |
| Figure 24: Kentucky Map of B/C Ratios .....   | 46 |
| Figure 25: Total Lane Miles by Number of Lanes and Facility Type .....                      | 48 |
| Figure 26: 2030 Total Number of Lanes (Mixed Use Facility).....                             | 49 |
| Figure 27: 2030 Total Number of Lanes (Mode Separated Facility).....                        | 50 |
| Figure 28: 2030 Number of Exclusive Truck Lanes.....  | 51 |

## LIST OF TABLES

|   |    |
|---|----|
| Table 1. Summary of Kentucky Interstate Mileage and Daily Vehicle Miles Traveled.....       | 3  |
| Table 2: Miles of Interstate by ADT and No. of Lanes (Rural/Urban).....                     | 4  |
| Table 3: Major Interstate Sections Used for Traffic Trends Analysis .....                   | 6  |
| Table 4: Historical Traffic Volume Growth Rates .....                                       | 10 |
| Table 5: Projected Traffic Volume Annual Growth Rates (Percent).....                        | 19 |
| Table 6: 2003 Total Annual Recurring Delay (veh-hrs).....                                   | 25 |
| Table 7: 2030 Total Annual Recurring Delay (veh-hrs).....                                   | 25 |
| Table 8. Interstate Fatality Crash Rates in Kentucky as Compared to the United States ..... | 30 |
| Table 9. Summary of Crashes and Crash Rates for Kentucky Interstates .....                  | 31 |
| Table 10. Summary of Truck Crash Rates for Kentucky Interstates .....                       | 32 |
| Table 11. Summary of Overall Crash Rates by Number of Lanes for Kentucky Interstates.....   | 32 |
| Table 12. Summary of Truck Crash Rates by Number of Lanes for Kentucky Interstates .....    | 33 |
| Table 13: Sections with Critical Rate Factors > 1.0 (All Crashes).....                      | 34 |
| Table 14: Sections with Critical Rate Factors > 1.0 (Commercial Vehicle Crashes).....       | 35 |
| Table 15: Summary of Crash Rates by Peak Hour LOS.....                                      | 38 |
| Table 16: Summary of Crash Rates by Peak Hour V/C Ratio .....                               | 38 |
| Table 17: Summary of Commercial Vehicle Crash Rates by Peak hour LOS .....                  | 39 |
| Table 18: Summary of Commercial Vehicle Crash Rates by Peak hour V/C Ratio.....             | 39 |
| Table 19: Summary of Crash Rates by Number of Lanes and Interchange Density .....           | 39 |
| Table 20: Crash Rate Regression Model Variables .....                                       | 40 |
| Table 21: Comparison of Regression Model and Average Values.....                            | 40 |
| Table 22: Recurring Delay by Existing No. of Lanes (Veh-hrs) .....                          | 43 |
| Table 23: Non-Recurring Delay by No. of Lanes and Alternative (Veh-hrs) .....               | 44 |
| Table 24: Predicted Annual Crashes by Existing No. of Lanes and Alternative.....            | 44 |
| Table 25: HPMS Sections with Highest B/C Ratio .....  | 45 |

## EXECUTIVE SUMMARY

This analysis and evaluation is directed toward assessing safety and capacity issues on interstates in Kentucky and, particularly, the manner in which commercial vehicle traffic affects these issues. Analyses was undertaken to show past trends and project future traffic. Previous research was relied upon to show the level of safety on each of the interstates relative to statewide averages. Analyses were performed to evaluate the impact on safety when comparing segments by number of lanes available for through traffic (4, 6, and 8-lane highway sections). Delay on the interstates was calculated based on closure times due to crashes and estimates were made of the relative impact if additional lanes were available. Volume versus capacity assessments were performed to show the operational level of each interstate. Insight and knowledge gained from other similar studies were considered and incorporated where appropriate.

Following is a summary of the primary conclusions resulting from analysis and evaluation of the safety, capacity, and delay issues related to interstates in Kentucky.

### ***Future Traffic Projections***

- A clear upward trend in historical volumes has been observed on all interstate sections in Kentucky.
- Since the mid-1970's, annual growth in interstate traffic volumes has averaged 3.46 percent, which is a greater rate of increase than observed on non-interstate facilities and represents an approximate doubling of traffic every 20 years.
- Future growth in traffic on Kentucky interstates is projected to increase at a rate of 2.0 to 2.5 percent per year.

### ***Recurring Congestion***

- Under 2003 conditions, 30 miles of interstate were found to operate at LOS F during the peak period, primarily on urban interstate sections.
- For 2030 projected traffic volumes, approximately 390 miles of interstate are expected to operate at LOS F, with 45 percent being rural interstate sections.
- Even though 80 percent of the total mileage and 60 percent of the total VMT on the study interstates occurred on rural interstates, less than one percent of the 2003 recurring delay occurred on rural interstates under 2030 conditions, rural interstates accounted for 36 percent of recurring congestion.
- Recurring traffic delay is expected to increase from 43 million vehicle-hours annually under 2003 demand to 860 million vehicle-hours in 2030.

### ***Non-Recurring Congestion***

- Average incident duration for urban and rural interstates was calculated to be 0.76 hours and 1.12 hours, respectively.
- Rural interstates were shown to account for almost 20 percent of non-recurring delay, compared to less than 0.01 percent of recurring delay, for 2003 conditions. Projecting 2030 conditions, rural interstates were shown to account for almost 40 percent of non-recurring delay (36 percent of recurring congestion).



- Non-recurring delay was shown to provide significantly higher total delays compared to recurring congestion for both the existing and future conditions.
- Because highway incidents are unpredictable, the resulting non-recurring congestion can be more disruptive and costly than recurring peak hour congestion.

### ***Crash Rates***

- The fatal crash rate on interstates in Kentucky is less than the national rate.
- Interstates have a much lower crash rate than other highway types.
- The total and injury crash rates for commercial vehicles on interstates are less than the corresponding overall rates.
- The fatal crash rate for commercial vehicles on interstate facilities is higher than the overall fatal rate.
- The overall crash rate is very similar on 4-lane and 6-lane interstates.
- The overall crash rate is less on 8-lane interstates as compared to 4-lane and 6-lane interstates.
- The crash rate for commercial vehicles is less on rural 6-lane interstates as compared to rural 4-lane interstates.
- For commercial vehicles on urban interstates, there is a pattern of increasing crash rates with increasing number of lanes.
- There were 48 interstate sections identified as having a critical overall crash rate.
- There were 26 interstate sections identified as having a critical commercial vehicle crash rate.

### ***Crash Rates and Operational Performance***

- Overall crash rates generally increased with degradation of LOS and V/C.
- Commercial vehicle crash rates also increased with degradation of LOS and V/C.
- Crash rates generally increased with an increase in interchange density.
- Of the variables considered to predict changes in crash rates due to changes in lane configurations, the most significant contributors to total crash rates on interstates were ADT and interchange density.

### ***Alternative Analysis***

- For the Build Alternative of expanding existing interstates from 4 to 6 lanes and 6 to 8 lanes, recurring and non-recurring congestion is expected to be reduced by 99 percent and 25 percent, respectively, under 2003 traffic demand and by 69 percent and 35 percent under 2030 traffic demand.
- For the Build Alternative of expanding exiting interstates from 4 to 6 lanes and 6 to 8 lanes, there were 110 of 161 sections evaluated with a B/C ratio greater than 1.0. 57 of these sections showed a B/C ratio greater than 2.5.
- Of the 10 sections with the highest B/C ratios, 8 are 4-lane facilities, 7 of which are rural interstates.
- Widening interstates to provide exclusive truck lanes was not shown to be as effective as widening for mixed-use facilities on a statewide level.

## 1. INTRODUCTION

The Interstate Highway System was established as part of the Federal Highway Act of 1944; however, funding for construction was not provided until 1956 when the completion of a “National System of Interstate and Defense Highways” was declared essential to the national interest. The original purposes of the Interstate System were to provide for efficient long-distance travel, support defense, and connect metropolitan and industrial areas. A study by the Government Accounting Office (GAO) noted that through 2001, the federal government had invested over \$370 billion on interstates as apportionments to states (1). It was also reported in this GAO study that a survey of state transportation officials found that the most important role of the Interstate System, other than supporting safe travel, was moving freight traffic across their states. The use of the Interstate System was further defined with the national statistic that truck traffic on the interstates accounted for over 41 percent of the total truck miles traveled in 2000.

As the Interstate System was planned and designed for Kentucky in the 1960’s, commercial vehicles were estimated to be a relatively minor fraction of the overall composition of traffic. However, due to changes in the transportation segment of the economy of the United States, unexpected increases have occurred in the commercial vehicle component of the freight delivery system. Commercial vehicle traffic on the major interstates in Kentucky has grown to higher than expected levels. Presently, I-65 averages approximately 35 percent trucks and the proportion of trucks on I-24, I-71 and I-75 is slightly less at about 30 percent. I-64 averages about 23 percent trucks. Average vehicles per day are nearly 50,000 on I-65 and I-75, and more than 30,000 on I-64 and I-71.

The patterns of total traffic and truck traffic on interstates in Kentucky reflect the overall traffic patterns occurring elsewhere in the United States. Interstates represent a major portion of the transportation system that is available for freight shipments. Based on the 2002 Commodity Flow Survey by the Bureau of Transportation Statistics, shipments of freight have shown a steady increase in the past several years and now more than 10 percent of the U.S. Gross Domestic Product is related to transportation activity (2). Only housing, health care, and food contributed a larger share of the Gross Domestic Product than transportation based on 2004 data from the Bureau of Transportation Statistics. Highways continue to be the dominant mode of transport for all freight shipments. The 2002 Commodity Flow Survey shows trucks accounting for 64 percent of the total value shipped and 58 percent of the tons of freight shipped.

Overall traffic on interstates in Kentucky has not shown dramatic increases in the past few years; however, truck traffic has shown greater increases. Results compiled from analysis of automatic vehicle classification data show an increase of 18.1 percent in overall traffic on all interstates in Kentucky for the period 1996 to 2002, as compared to an increase of 27.3 percent for truck traffic for the same time period.

Kentucky, as well as most other states, has been reconstructing and rehabilitating the interstate system to improve safety and increase capacity; however, in many cases the improvements have failed to match the increasing traffic demands, especially commercial vehicle traffic. Issues associated with freight movement along the interstate corridors that will require continued attention include safety factors associated with commercial vehicle traffic, the decreased life cycle of the interstate system due to increased weights carried by commercial

vehicles, and congestion and air quality issues associated with commercial vehicles (especially in urban areas).

Other studies have been undertaken to assess strategies and solutions for the increasing demands placed on the interstate system by overall growth of truck traffic. One of the most comprehensive and progressive projects being proposed to address increasing truck traffic and capacity on interstates is the I-81 STAR Solutions Project in Virginia (3). This project will upgrade all 325 miles of I-81 in Virginia and provide at least four lanes in each direction with at least two lanes dedicated to truck traffic. Directional dual interchanges with truck flyovers are proposed along with truck climbing lanes and additional truck-only rest areas. A major objective of this project is to separate passenger vehicles from trucks and therefore reduce the frequency of crashes and other incidents that result in injuries and major delays on the interstate. A public-private partnership approach is proposed to address the project development, construction, and management of this project.

Another study underway is the National I-10 Freight Corridor Study (4). This study has as its objectives to assess the economic importance of freight movements on I-10, to identify traffic operations and safety problems which impede freight flow, and to identify strategies to facilitate freight flow in the corridor.

A study by the Reason Public Policy Institute in 2004 also addressed the safety and capacity problems of the interstate system (5). The approach taken in the study was to identify interstate corridors where toll truckways could be implemented. These toll truckways would be heavy-duty, barrier-separated new lanes added to interstates on which it would be legal to operate double and triple-trailer combination vehicles.

The Trans Texas Corridor involves a 4,000-mile network of existing interstates and proposes separate lanes for passenger cars and trucks, as well as separate rail lines for passenger and freight transport (6). The project's objective is faster, safer, and less congested traffic flow. Other anticipated benefits include the safer transport of hazardous materials, improved air quality, and economic development.

## **2. SCOPE**

This analysis and evaluation is directed toward assessing safety and capacity issues on interstates in Kentucky and, particularly, the manner in which commercial vehicle traffic affects these issues. Analyses was undertaken to show past trends and project future traffic. Previous research was relied upon to show the level of safety on each of the interstates relative to statewide averages. Analyses were performed to evaluate the impact on safety when comparing segments by number of lanes available for through traffic (4, 6, and 8-lane highway sections). Delay on the interstates was calculated based on closure times due to crashes and estimates were made of the relative impact if additional lanes were available. Volume versus capacity assessments were performed to show the operational level of each interstate. Insight and knowledge gained from other similar studies (I-10 along the southern tier of the United States, I-81 in Virginia, and the Trans Texas Corridor) were considered and incorporated where appropriate.

### 3. EXISTING CONDITIONS

#### 3.1 ROADWAY CHARACTERISTICS

As in nearly all areas of the United States, the system of interstate highways in Kentucky represents a significant component of highway transportation. Interstates in Kentucky carry high traffic volumes and most segments also have relatively high percentages of commercial truck traffic. Even though the 763 miles of interstates in Kentucky represents less than 1.0 percent of total statewide mileage, more than 25 percent of the overall vehicle miles traveled occur on interstates. Except for a few instances in commercial or industrial areas with predominantly truck traffic, the interstates in Kentucky carry a higher percentage of truck traffic than other highways. The generally rural interstates (I-24, I-64, I-65, I-71, and I-75) have truck percentages that range from approximately 25 to 35 percent, while the urban bypass interstates (I-264, I-265, I-275, and I-471) have truck percentages in the 5 to 15 percent range. Presented in Table 1 is a summary of interstate mileage and Vehicle Miles of Travel (VMT), categorized by rural and urban sections. This table shows that 553 miles, or 72 percent of the overall mileage, is categorized as rural. However, only 52 percent of the overall travel occurs on rural interstates. When considering only truck traffic, the predominate location of travel is on rural interstates with 68 percent of the vehicle miles traveled categorized as rural.

Table 1. Summary of Kentucky Interstate Mileage and Daily Vehicle Miles Traveled (Thousands)

| Route                          | Rural Miles | Urban Miles | Total Miles | Rural VMT | Urban VMT | Total VMT |
|--------------------------------|-------------|-------------|-------------|-----------|-----------|-----------|
| <i>I-24</i>                    | 76.8        | 16.5        | 93.4        | 1,533     | 546       | 2,079     |
| <i>I-64</i>                    | 163.6       | 21.6        | 185.2       | 4,500     | 1,990     | 6,490     |
| <i>I-65</i>                    | 104.7       | 32.7        | 137.3       | 4,104     | 2,975     | 7,079     |
| <i>I-71</i>                    | 55.9        | 21.9        | 77.7        | 1,584     | 1,229     | 2,814     |
| <i>I-75</i>                    | 146.2       | 45.6        | 191.8       | 5,808     | 3,773     | 9,581     |
| <i>I-264</i>                   | N/A         | 22.9        | 22.9        | N/A       | 2,421     | 2,421     |
| <i>I-265</i>                   | N/A         | 24.5        | 24.5        | N/A       | 1,552     | 1,516     |
| <i>I-275</i>                   | 5.4         | 19.1        | 24.6        | 181       | 1,459     | 1,632     |
| <i>I-471</i>                   | N/A         | 5.0         | 5.0         | N/A       | 471       | 471       |
| <i>Total (All Interstates)</i> | 552.5       | 209.9       | 762.4       | 17,711    | 16,407    | 34,118    |

This study analyzed the operational, safety and incident closure characteristics of Interstates 24, 64, 65, 71 and 75 in Kentucky. The study roadways and urban boundaries are shown in Figure 1. This data set includes all Kentucky interstates except urban bypass routes (I-264, I-265, I-275 and I-471). In addition, the 3.8 mile, 7-lane section of I-75 in northern Kentucky was removed from the data set due to the number of lanes, which is unique to this section, and its unusual crash and operational characteristics related to the volumes, grade, interchange density and adjacent constraints across the Ohio River.

Roadway and volume data were obtained from the Kentucky Transportation Cabinet (KYTC) Highway Performance Monitoring System (HPMS). The most recent data available from 2003 was used. Use of the HPMS provided access to a wide range of information including Average Daily Traffic (ADT), shoulder/lane widths, number of lanes etc.

The study data set includes 681.6 of the 763 total miles of urban and rural interstates in Kentucky. This represents 161 of the 201 total sections of interstate highways in the HPMS. The study routes have varying lane configurations including four, six and eight-lane sections with volumes ranging from 13,000 ADT to 165,000 ADT. Table 2 summarizes the lane and ADT characteristics of the data set. Appendix A contains a full list of each HPMS section and roadway and traffic characteristics.

Table 2: Miles of Interstate by ADT and No. of Lanes (Rural/Urban)

| ADT            | Urban   |         |         | Rural   |         |         | Total   |
|----------------|---------|---------|---------|---------|---------|---------|---------|
|                | 4-Lanes | 6-Lanes | 8-Lanes | 4-Lanes | 6-Lanes | 8-Lanes |         |
| < 50,000       | 28.0    | 19.3    | 2.7     | 437.1   | 54.1    | 0.0     | 541.166 |
| 50,000-100,000 | 27.8    | 22.2    | 2.1     | 13.0    | 43.0    | 0.0     | 108.058 |
| 100,000+       | 1.8     | 18.7    | 11.9    | 0.0     | 0.0     | 0.0     | 32.382  |
| <i>Total</i>   | 57.7    | 60.2    | 16.7    | 450.0   | 97.1    | 0.0     | 681.606 |

As can be seen from the tables and Figure 1, the majority of four-lane facilities are located on rural routes, though approximately 58 miles of four-lane facilities still exist within urban boundaries of Kentucky. Sections of four-lane interstates accommodate traffic volumes over 52,000 ADT on rural facilities and over 120,000 ADT on urban sections of I-64.

Six-lane interstates are represented with 97 miles in rural areas and 60 miles in urban areas. These facilities serve volume ranges between 30,000 ADT and 85,000 ADT on rural sections, and over 160,000 ADT on some urban sections of I-75 in northern Kentucky.

All 24 miles of 8-lane interstate are located within urban areas and serve volumes between 40,000 ADT on I-65 and 140,000 ADT on I-75 in northern Kentucky.

Figure 1: Study Roadway and Urban Boundary Map

### 3.2 HISTORICAL TRAFFIC GROWTH

For the purpose of analyzing traffic volume trends the major interstates in Kentucky were segmented as shown in Table 3, below. Traffic volume data were obtained from the Kentucky Transportation Cabinet traffic count history file (CTS). The CTS file contains all counts that have been made from 1963 to the present, and utilizes an algorithm to generate a current year estimate (2004 for this study) if a count was not made during that year. For this study, the years 1963 - 1974 were not considered because of missing data for many stations, and also because 1973 counts were abnormally high for many stations (for I-24 the count history used began in 1980 because of missing data for many stations in prior years). Traffic volume trends were then developed and analyzed for each of the nine major segments using the average count for each year (for this purpose, missing year data was estimated so that average values would reflect all stations for all years).

Table 3: Major Interstate Sections Used for Traffic Trends Analysis

| Segment       | Description                   | Length | No. Sections | ADT Range        | Average ADT |
|---------------|-------------------------------|--------|--------------|------------------|-------------|
| <i>I-24</i>   | All Sections                  | 93.4   | 23           | 14,700 - 41,200  | 22,952      |
| <i>I-64 W</i> | Jefferson thru Fayette County | 83.2   | 30           | 27,200 - 171,000 | 52,601      |
| <i>I-64 E</i> | East of Fayette County        | 102.0  | 22           | 12,800 - 43,700  | 20,311      |
| <i>I-65 S</i> | South of Western KY Parkway   | 91.1   | 25           | 29,000 - 51,200  | 38,296      |
| <i>I-65 N</i> | North of Western KY Parkway   | 46.2   | 17           | 44,700 - 164,000 | 90,923      |
| <i>I-71 S</i> | Jefferson County              | 11.3   | 4            | 54,800 - 70,000  | 60,996      |
| <i>I-71 N</i> | North of Jefferson County     | 66.4   | 18           | 24,500 - 58,000  | 32,959      |
| <i>I-75 S</i> | South of Fayette County       | 97.7   | 21           | 23,100 - 61,800  | 37,805      |
| <i>I-75 N</i> | Fayette thru Kenton County    | 94.1   | 38           | 32,800 - 175,000 | 65,612      |

Figures 2 through 6 display the historical traffic volume trends for each segment. A clear upward trend in the average traffic volume can be seen in every case, and in most cases the trend is remarkably stable and can be approximated relatively well by a straight line (the  $R^2$  correlation coefficient for a straight line curve fit is 0.92 or better in all cases).

Figure 2: Interstate 24 Historical Traffic Growth

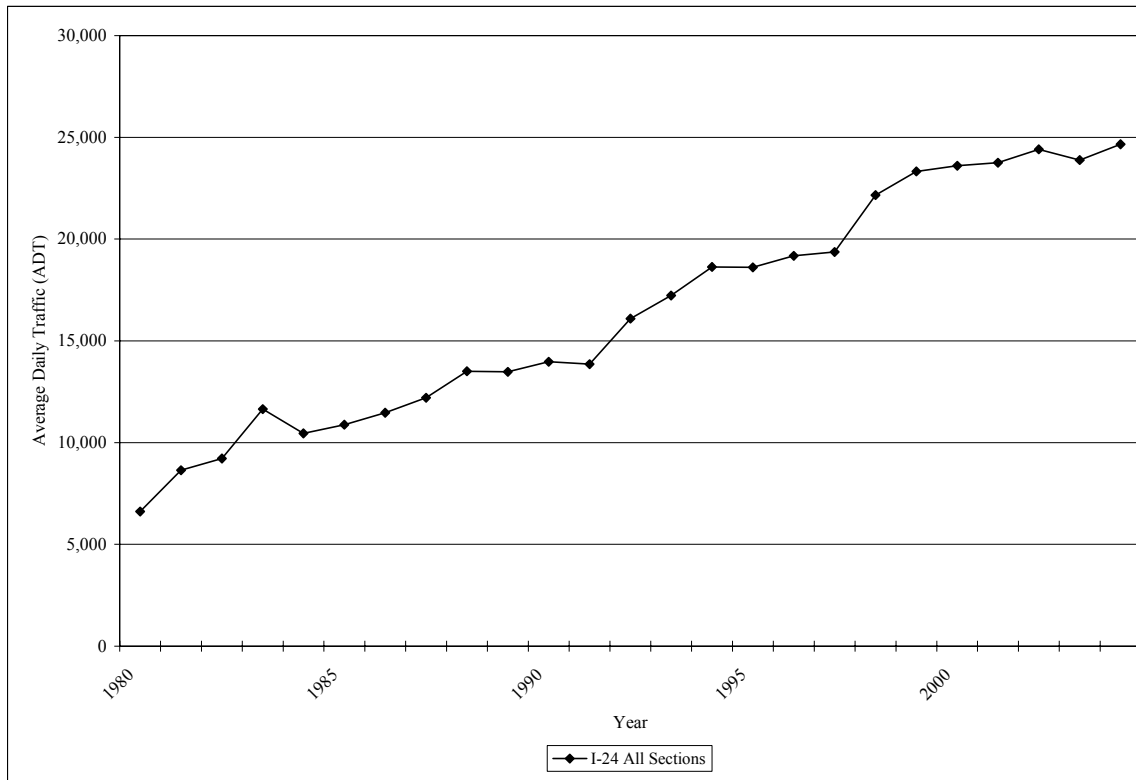


Figure 3: Interstate 64 Historical Traffic Growth

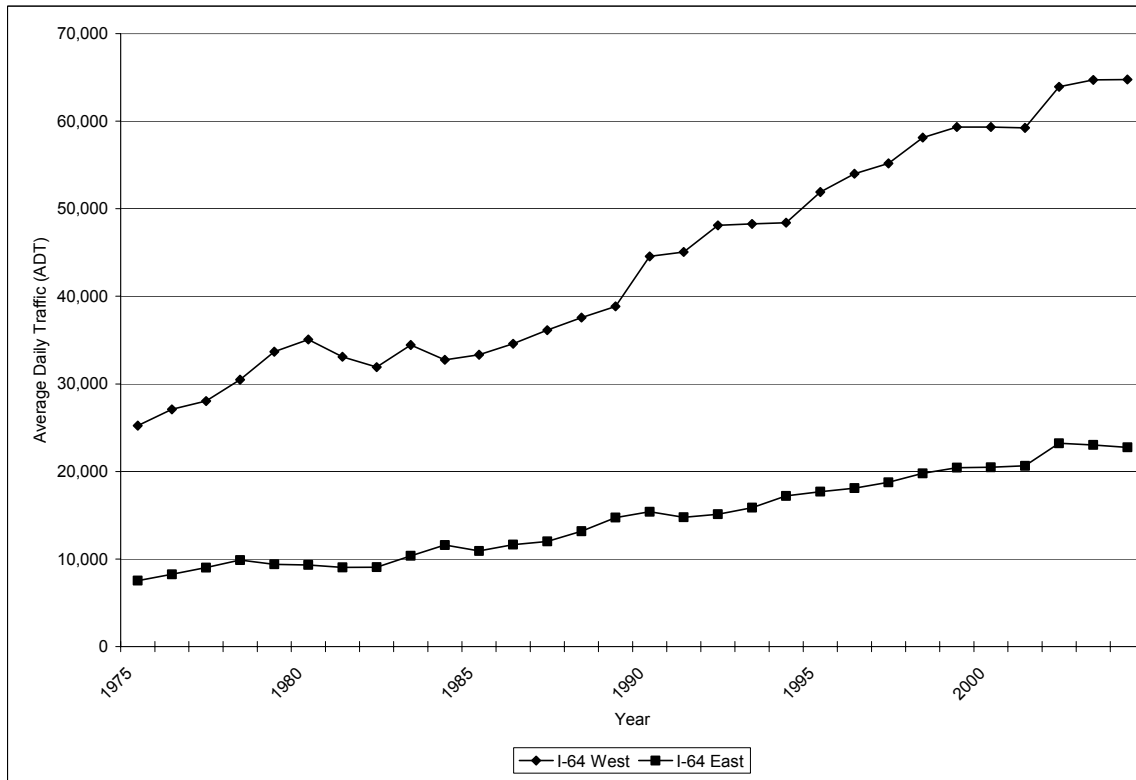




Figure 4: Interstate 65 Historical Traffic Growth

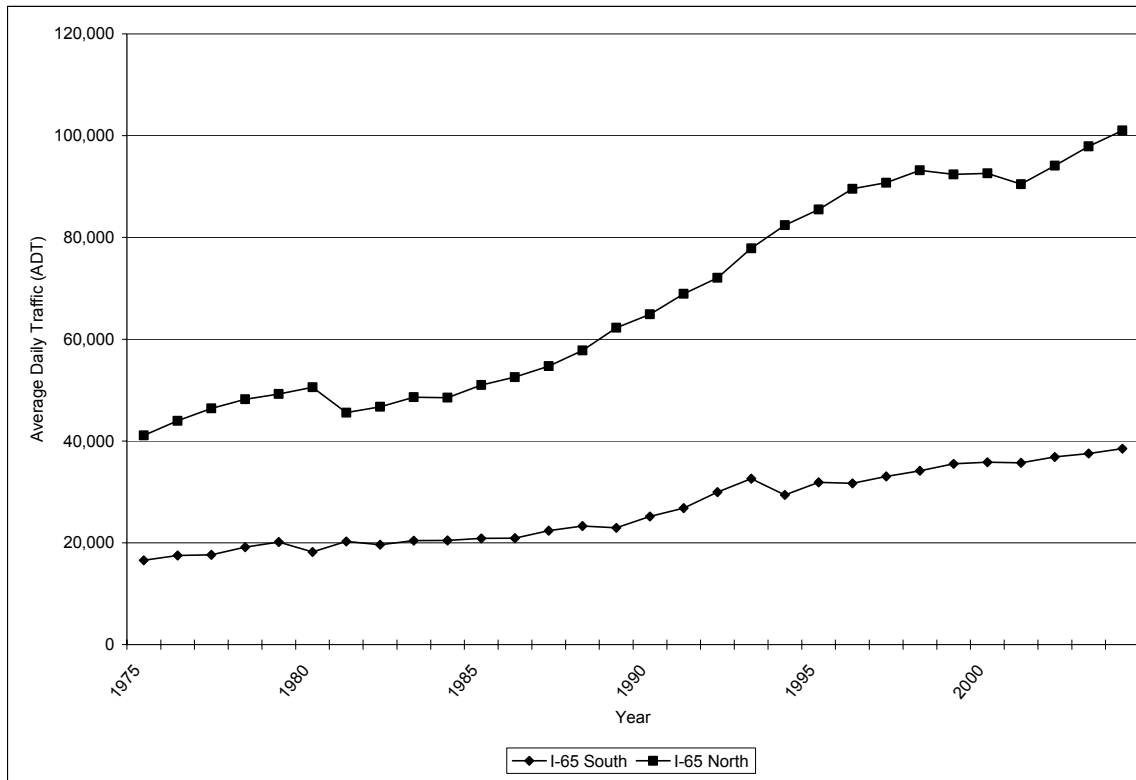


Figure 5: Interstate 71 Historical Traffic Growth

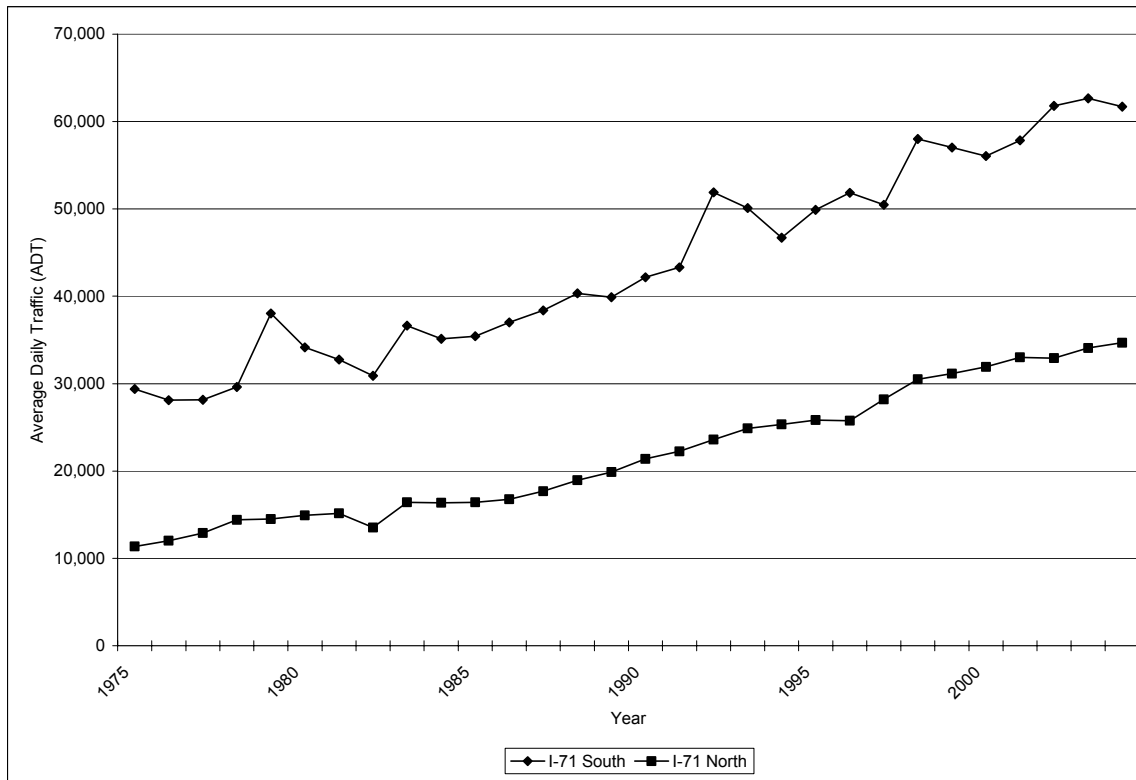
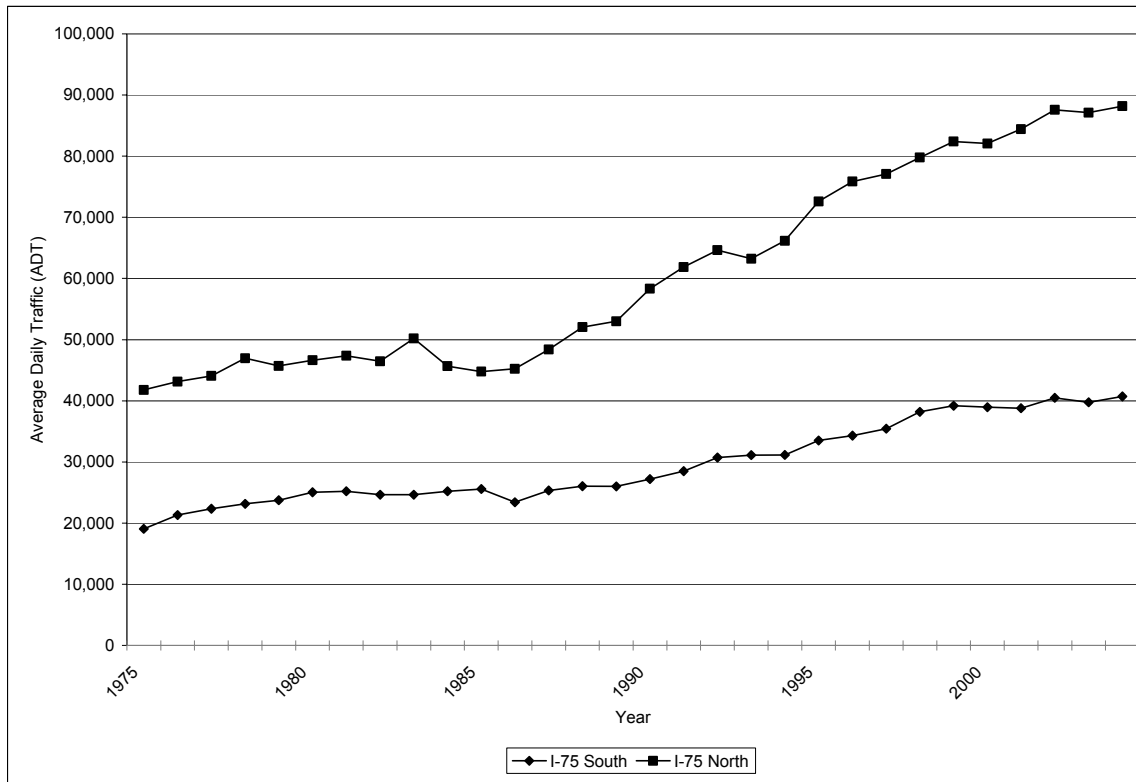


Figure 6: Interstate 75 Historical Traffic Growth



It is often convenient to express traffic growth in terms of an annual percentage growth rate. The growth rates exhibited over the periods analyzed here are shown in Table 4. It should be noted that the growth rate calculated for I-24 is somewhat of an anomaly due to the low volume in the first year and the fact that traffic volumes on this route nearly doubled in the first three years of the time period examined. For the last 20 years of this period, the annual growth rate was 4.38 percent.

Table 4: Historical Traffic Volume Growth Rates

| <b>Segment</b> | <b>Annual Growth Rate</b> |
|----------------|---------------------------|
| <i>I-24</i>    | 5.64%                     |
|                |                           |
| <i>I-64 W</i>  | 3.30%                     |
| <i>I-64 E</i>  | 3.88%                     |
|                |                           |
| <i>I-65 S</i>  | 2.95%                     |
| <i>I-65 N</i>  | 3.15%                     |
|                |                           |
| <i>I-71 S</i>  | 2.59%                     |
| <i>I-71 N</i>  | 3.92%                     |
|                |                           |
| <i>I-75 S</i>  | 2.65%                     |
| <i>I-75 N</i>  | 2.61%                     |

The rates tabulated above are consistent with the latest estimates of historical statewide vehicle miles of travel (VMT) growth for interstates throughout Kentucky that have been prepared by KYTC (3.46 percent per year for the period 1980 - 2003) and are substantially higher than similar growth rates for non-interstate highways (2.49 percent per year.). The growth indicated here represents an approximate doubling of traffic every 20 years.

#### **4. PROCESSES AND PROCEDURES**

Safety and operational characteristics for study interstate segments were compiled and summarized for alternative analysis and evaluation to identify the most beneficial interstate configurations to optimize safety and operational performance. The primary objective of this effort was to establish relationships between crash and operational performance. The study examined three primary characteristics:

- Recurring Congestion and Delay
- Non-Recurring Congestion and Delay
- Crash Rate

The base conditions for interstates in Kentucky were compiled and summarized for comparison with other interstates within Kentucky as well as national statistics for interstates. With the focus of the study on safety and capacity, these were the statistics of interest. Sources of information were the HPMS database and the Highway Statistics report compiled by FHWA

(7, 8, 9). Kentucky-specific crash data were available from the same Highway Statistics report and statistics compiled in the annual crash rate report prepared by the Kentucky Transportation Center (10). Additional analysis of the CRASH database was necessary in order to obtain the crash rate detail necessary for this study.

After quantifying each of these characteristics, relationships between operational performance and safety performance were identified. Alternative analysis was then conducted to identify the potential benefits of alternative lane configurations on study interstate sections under existing, 2003 conditions, and future year (2030) traffic demand.

The following sections outline the methodologies used to quantify safety and operational characteristics, and the analysis procedures used to evaluate alternative lane configurations.

#### **4.1 FUTURE TRAFFIC PROJECTIONS**

This study examined traffic volume projections using four basic methodologies:

- KYTC statewide traffic model (SWM)
- KYTC traffic counts history file forecasting algorithm (CTS)
- Linear trendline projections
- Polynomial trendline projections

The current version of the SWM was developed for a base year of 1999 and a forecast year of 2030. The SWM is a traditional three-step model using an all-or-nothing assignment procedure.

The CTS forecasting algorithm was developed for KYTC by the Kentucky Transportation Center during the 1987 study titled “Traffic Volume Estimates and Growth Trends” (11). The CTS generates 20-year forecasts at each traffic count station using actual count data and a piecewise linear regression procedure (2024 projections were extended to 2030 using the annual growth rate indicated by the 2024 value).

Linear and polynomial trendline projections were developed using the nine major segments discussed in the existing conditions Section 3.2 and are based on the average count over the section for each year.

#### **4.2 OPERATIONAL ANALYSIS**

Operational analysis was conducted for each segment of the study interstates for the existing (2003) traffic demand and future year (2030) traffic demand. The primary objective of this analysis was to quantify the user costs associated with delay on the Interstate System. As such, operational analysis examined both recurring congestion and delay resulting from daily travel patterns, and non-recurring congestion and delay resulting from incidents on the Interstate System.

### 4.2.1 Recurring Congestion

In order to evaluate the changing operational characteristics of the roadway over the period of the day due to changes in traffic volumes, operational analysis was performed on a total of four volume scenarios for each section. Volume scenarios were based on average hourly distribution data for urban and rural interstates provided in the KYTC Kentucky Traffic Forecasting Report 2004 (12). For the purposes of this analysis traffic volumes were divided into four different time periods.

- Period 1: Overnight Period
- Period 2: Off-Peak Period
- Period 3: Peak Shoulder Period
- Period 4: Peak Period

Figure 7 shows the hourly distribution for rural and urban interstates and defines each period identified above. Figure 8 shows the average hourly distribution (K Factor) by period.

Figure 7: Average Hourly Volume Distribution

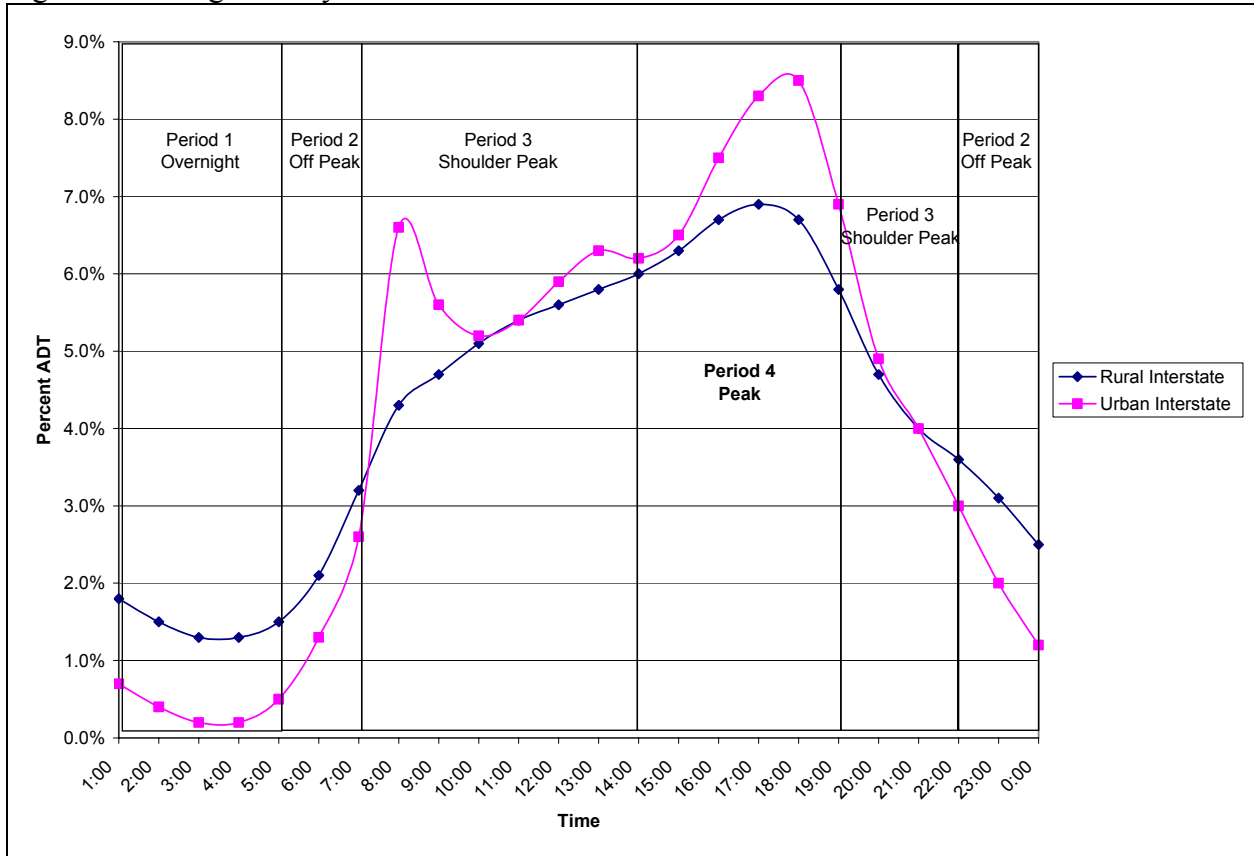
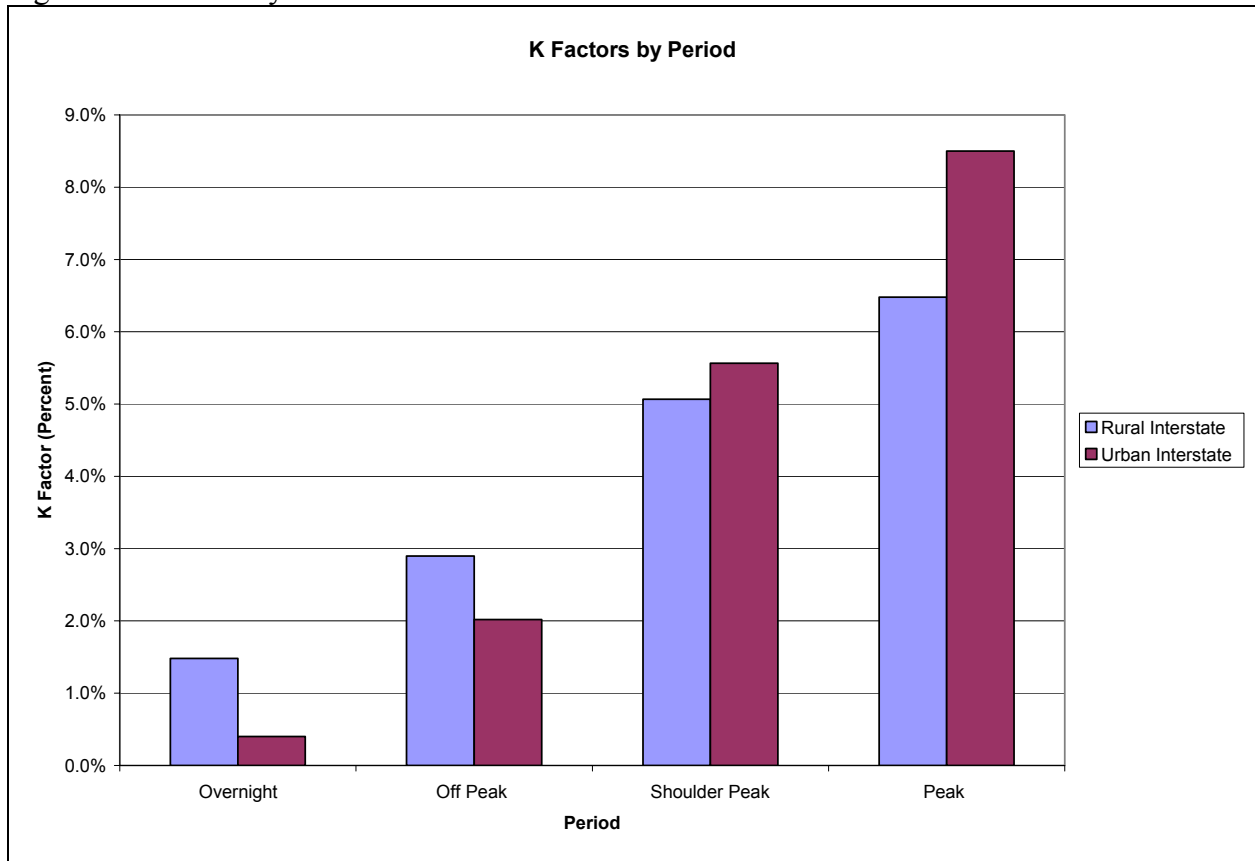


Figure 8: K Factor by Period



Representative hourly volumes for each HPMS section and volume scenario were determined by multiplying the average hourly distribution for the volume scenario by the ADT for the section and by the directional factor of the HPMS section. Hourly volume calculations are shown in Equation 1.

$$\text{Hourly Volume (vph)} = K * D * \text{ADT} \quad (1)$$

Where  $K$  = Hourly Volume (Percent of ADT) from Figure 7  
 $D$  = Directional Factor (0.5 for all periods except Peak Period)  
 $ADT$  = Average Daily Traffic (From HPMS)

Once the hourly volume was determined for each period examined, roadway capacity was determined for each HPMS section per period based on the FHWA document titled “Procedures for Estimating Highway Capacity” from the HPMS Field Manual (13). Level of service (LOS) and V/C ratios were determined for each HPMS section and period based on this capacity estimate using Highway Capacity Manual (HCM) methodology.

## 4.2.2 Non-Recurring Congestion

### 4.2.2.1 Non-Recurring Congestion (Existing Conditions)

Non-recurring congestion and delay due to incidents was also estimated for each segment of the study interstates. Road closure information was only available through the Collision

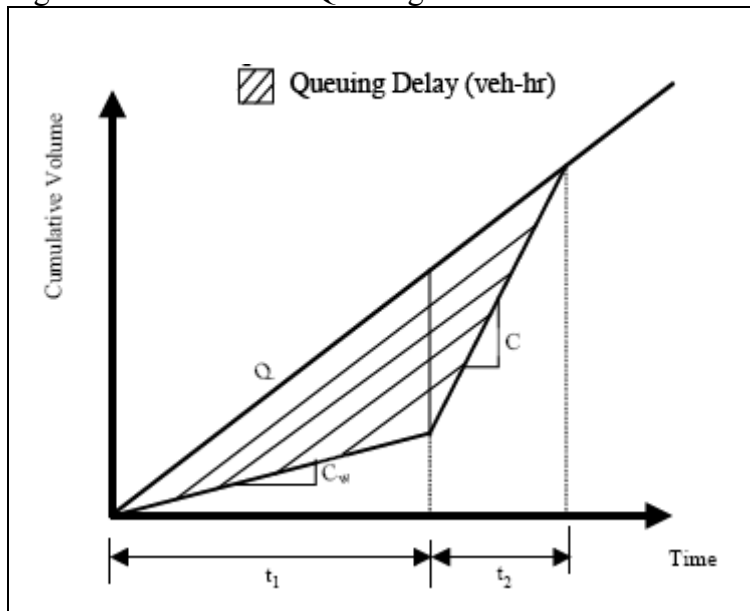
Report Analysis for Safer Highways (CRASH). Therefore, only incident delay due to crashes was estimated. Non-Recurring congestion caused by other incidents such as stalled vehicles, weather, construction/maintenance activities etc., were not included in this study.

For the three-year study period 8,511 incidents were reported on the study interstates where the road was fully or partially closed. Based upon the route number and mile point from the crash report, incidents were assigned to their respective HPMS segment.

Incident delay was estimated using a deterministic queuing model to estimate the delay caused by both the actual road closure time ( $t_1$  in Figure 9) and the queue clearing time ( $t_2$ ) after the closure was cleared. This methodology will allow for improved evaluation of lane configuration alternatives in terms of evaluating the queue clearing capacity. The deterministic model depends on the demand volume ( $Q$ ), freeway capacity ( $C$ ), incident capacity ( $C_i$ ) and incident duration ( $t$ ), and is given by Equation 2 and shown in Figure 9. (14)

$$\text{Delay (veh-hr)} = \frac{t^2(C-C_i)(Q-C_i)}{2(C-Q)} \quad (2)$$

Figure 9: Deterministic Queuing Model



Roadway volume ( $Q$ ) was determined by identifying the period in which the incident occurred, given by time of incident, and applying the appropriate  $K$  and  $D$  factors for that period as described above in section 3.3.1.

Roadway capacity ( $C$ ) was determined in accordance with the HPMS procedures outlined in section 3.2.1. Roadway capacity was developed for each period. A 30 percent reduction of average daily truck traffic was assumed to calculate the heavy vehicle factor for the peak period.

The crash report does not provide any information on the extent of the road closure, i.e. one lane closed, two lanes closed, all lanes closed etc., which is needed to determine the incident

capacity ( $C_i$ ). Therefore, vehicle delay caused by the incident was calculated using a reduced capacity equivalent to closing one lane and a capacity of zero indicating closure of all lanes. The average delay of these two scenarios was calculated and used as the delay estimate for the incident. Incident delay was only calculated for one direction. Reductions in roadway capacity in the opposing direction, due to rubber-necking, closure by emergency personnel, etc., were not considered in this analysis.

Incident Duration ( $t$ ) is the duration of time between the notification of the incident and the time reported clear on the crash report filed by the responding officer.

One limitation of this method is that incident delay cannot be determined on roadways that are operating over capacity under normal conditions. This limitation can cause problems when estimating non-recurring delay during peak periods in urban settings. Under these conditions incident delay was not estimated.

#### **4.2.2.3 Non-Recurring Delay (Alternative Analysis )**

In addition to evaluating non-recurring delay for the existing conditions, it was also necessary to establish a procedure for determining incident delay for alternative analysis as described below. Therefore an incident rate was calculated for each HPMS section in terms of incidents per million vehicle miles traveled (MVM) based on the existing conditions. This incident rate was then applied to existing and alternative lane configurations for the current and future design years, 2003 and 2030 respectively, based on estimated VMT. Annual incident delay was calculated using average incident durations for rural and urban interstate incidents to calculate the predicted annual delay for the No Build and Alternative Scenarios (*See Section 4.2.1*).

One limitation of this method is that it does not account for a potential change in the incident pattern due to changes in the lane configuration. It does, however, allow for estimation of the delay reduction due to additional roadway capacity. Other methods were used to determine the potential change in crash frequency related to changes in the total number of lanes on the facility, as described below.

### **4.3 SAFETY ANALYSIS**

#### **4.3.1 Crash Rates (Existing Conditions)**

Kentucky-specific crash data were available from the Highway Statistics reports (7,8,9) and statistics compiled in the annual crash rate report prepared by the Kentucky Transportation Center (10).

A detailed crash analysis was conducted using the CRASH database for a three-year study period from July 1, 2001 through June 30, 2004. Based upon the route number and mile point documented in the crash report, crashes were assigned to their respective HPMS section. Using the section length and average daily traffic (ADT) reported in the HPMS for each section, vehicle miles traveled was calculated. Based on this information crash rates were calculated for each HPMS section in terms of crashes per MVM. Crash rates were developed for all crashes, as well as injury and fatal crashes.



Involvement of commercial vehicles in crashes was determined using the CRASH files. The number of commercial vehicles in a crash was determined for each HPMS section, as well as the percentage of vehicle miles traveled that could be associated with commercial vehicles in that section. This information was then used to calculate crash rates for commercial vehicles.

In addition, a critical rate and critical rate factor were calculated for each HPMS section. The critical rate is a measure of the probability that the crash rate for a specific section exceeds the average rate to a level of statistical significance considering the exposure (length and volume).

#### 4.3.2 Crash Rates (Alternative Analysis)

Once crash rates were determined for each HPMS section, a multi-variate regression model was developed to relate roadway and operational characteristics to crash rates. The regression model evaluated over 200 different variables including first and second order interactions between variables. Variables included ADT, number of lanes, interchange density, LOS and volume to capacity (V/C) ratios.

The regression model was evaluated using three distinct measures of fit.

- **Coefficient of determination ( $R^2$ ).** The percentage of total variation in the response that is explained by predictors or factors in the model.
- **Adjusted  $R^2$ .** Accounts for the number of predictors or factors in the model. Adjusted  $R^2$  is useful for comparing models with different numbers of predictors or factors. For example, adjusted  $R^2$  may actually decrease when another predictor is added to the model, because any decrease in error sum of squares may be offset by the loss of the degree of freedom.
- **Predicted  $R^2$ .** Predicted  $R^2$  indicates how well the model predicts responses for new observations, whereas  $R^2$  indicates how well the model fits existing data. Predicted  $R^2$  can prevent overfitting the model and is more useful than adjusted  $R^2$  for comparing models because it is calculated with observations not included in model calculation.

The primary purpose of the regression model is to aid in the prediction of crash rates for an alternative scenario to determine the safety impact of adding lanes to freeway segments. Therefore, the Predicted  $R^2$  value was optimized to improve model performance for evaluating “unknown” conditions.

Development of the regression allows for an estimate of changes in crash patterns due to changes in the number of lanes on an interstate facility, and corresponding changes in LOS, V/C and density. Identifying the relationship of other variables with crash rates provided better understanding of interstate crash trends and provides more accurate estimates than traditional crash analysis which applies average crash rates based on urban/rural designations and the number of lanes of the facility.

Operational characteristics of each HPMS section were calculated for the existing (No Build) and alternative (Build) lane configurations. The regression model was then applied to both configurations to determine the predicted crash rates for the section. Total annual crashes per section were calculated from the predicted crash rates based on annual VMT.

Existing (2003) crash rates were applied to future year (2030) traffic volumes to estimate the total number of crashes for the future year scenarios. The regression model was not applied to future year conditions as the ADT ranges are outside the bounds of ADT upon which the regression model was developed. Applying the 2003 crash rates for future year conditions is expected to provide a conservative estimate of future year crash rates as crashes would be expected to increase with increasing ADT.

#### 4.4 ALTERNATIVE ANALYSIS

In addition to identifying the safety and operational characteristics of the existing Interstate System, alternative analysis was conducted to evaluate alternative lane configurations to quantify the potential benefits of constructing additional lanes on the interstate system, beyond traditional capacity benefits. Alternative analysis included the evaluation of two alternatives for existing and future year conditions. These are:

- **No Build Alternative:** Existing number of lanes.
- **Build Alternative:** Widen existing 4-lane interstate facilities to 6 lanes and existing 6-lane facilities to 8 lane facilities. Under the Build Alternative, 8-lane facilities remained unchanged.

Alternative analysis was conducted to compare potential user cost savings between the existing conditions (No Build Alternative) and the Build Alternative. Applying the methodologies described above, annual recurring delay, non-recurring delay and crashes were determined for each HPMS section under existing (2003) and future year (2030) traffic demand for the No Build and Build Alternatives. Unit costs of cost per crash and cost per vehicle-hour of delay (veh-hr) were developed to quantify total benefits of the Build Alternative for each section. Alternative benefits were determined by Equation 3.

$$\text{Alternative Benefit (\$)} = \begin{aligned} & (C_{rNB} - C_{rBuild})(C_{Crash}) + \\ & (D_{1NB} - D_{1Build})(C_{Delay}) + \\ & (D_{2NB} - D_{2Build})(C_{Delay}) \end{aligned} \quad (3)$$

Where

- $C_r$  = Number of Crashes
- $D_1$  = Recurring Delay
- $D_2$  = Non-Recurring Delay
- $C_{Crash}$  = Unit Cost per Crash
- $C_{Delay}$  = Unit Cost per veh-hr of Delay

Costs per crash were developed based on national costs provided in the NHTSA report titled “Economic Impact of Motor Vehicle Crashes” (15). Costs were comprised of 1) injury components including medical, emergency services, market productivity, household

productivity, insurance administration, workplace and legal cost and 2) property damage. Unit costs provided in the report were adjusted based on Kentucky crash demographics of passenger and commercial vehicle percentages and vehicle occupancy rates. Average costs of \$5,163, \$19,936 and \$1,097,329 were used for PDO, injury and fatal crashes, respectively. An average weighted cost per crash of \$14,227 was used in the analysis based on Kentucky PDO, injury and fatal crash frequency.

Costs per vehicle-hour (veh-hr) of delay were developed from the Transportation Research Circular 477 (16) based on national average costs and occupancy for auto work, commute and non-work trips, and single unit and combination commercial truck costs. A cost of \$14.50/veh-hr, \$23.45/veh-hr and \$28.33/veh-hr was used for passenger car, single unit and combination trucks, respectively. An average cost per vehicle-hour of delay was developed based on passenger car, single unit and combination trucks percentages for each HPMS section.

Road widening costs per mile (one lane, both directions) were estimated at \$5.5 million for rural interstate sections and \$20 million per mile for urban interstate sections. These estimates were based on a review of recent estimates prepared for interstate widening projects in the Kentucky Transportation Cabinet's Unscheduled Projects List.

Based on roadway user costs and construction costs benefit-cost ratios were developed for each HPMS section. Benefits included projected crash and delay savings for the 27-year design period between 2003 and 2030. A straight line projection was used to interpolate annual savings between the existing year (2003) and future year (2030) estimated benefits. An interest rate of five percent was used to convert future savings to present worth. Project costs only included initial construction costs as described above. Potential increases in annual maintenance costs, due to widening, were not included in the analysis.

## **5. RESULTS**

### **5.1 INTERSTATE VOLUME PROJECTIONS**

The results of the four traffic prediction methods described in Section 4.1 are shown in Table 5, expressed as annual growth rates.

Table 5: Projected Traffic Volume Annual Growth Rates (Percent)

| Section                        | SWM Forecast | CTS Forecast | Trendline Forecasts |             | Average     |
|--------------------------------|--------------|--------------|---------------------|-------------|-------------|
|                                |              |              | Straight-Line       | Polynomial  |             |
| <i>I-24 All Sections</i>       | 2.25         | 2.61         | 2.35                | 2.66        | 2.47        |
| <i>I-64 W</i>                  | 1.74         | 2.47         | 1.84                | 2.94        | 2.25        |
| <i>I-64 E</i>                  | 2.08         | 2.43         | 1.89                | 3.07        | 2.37        |
| <i>I-65 S</i>                  | 2.43         | 2.15         | 1.70                | 2.76        | 2.26        |
| <i>I-65 N</i>                  | 1.65         | 2.19         | 1.73                | 2.93        | 2.13        |
| <i>I-71 S</i>                  | 1.88         | 1.99         | 1.61                | 2.61        | 2.02        |
| <i>I-71 N</i>                  | 2.01         | 2.49         | 1.82                | 3.23        | 2.39        |
| <i>I-75 S</i>                  | 2.08         | 2.12         | 1.50                | 2.95        | 2.16        |
| <i>I-75 N</i>                  | 1.89         | 2.37         | 1.55                | 3.49        | 2.33        |
| <i>High Value</i>              | 2.43         | 2.61         | 2.35                | 3.49        | 2.47        |
| <i>Low Value</i>               | 1.65         | 1.99         | 1.50                | 2.61        | 2.02        |
| <i>Range</i>                   | 0.78         | 0.62         | 0.85                | 0.88        | 0.45        |
| <b><i>Weighted Average</i></b> | <b>2.05</b>  | <b>2.35</b>  | <b>1.80</b>         | <b>3.00</b> | <b>2.30</b> |

An objective of this study was to evaluate the results of these traffic forecasting methodologies and select values deemed to be appropriate for analyzing future safety and traffic operational issues on the interstate system. In assessing these forecasted growth rates, it is helpful to start with an evaluation of the maximum/minimum values. With respect to the weighted averages for all interstate segments, the forecasted annual growth rates range from a low of 1.80 percent per year with the straight-line trend to a high of 3.00 percent per year with the polynomial trendline. Both of these extremes are judged to be plausible values given the many unknowns associated with projecting future traffic volumes. The 1.80 percent value would appear to be low when compared against historical growth on the interstate system. However, available highway capacity may begin to constrain interstate travel at some point in the future if capacity cannot be increased to match increasing demand, and this low forecast is probably within the realm of possibility from that perspective. Based on this argument, the 3.00percent value might be considered to be high, however this value matches well with historical growth (the polynomial trendline had slightly higher correlation statistics than the straight-line trend for all sections tested), and it should not be dismissed for that reason. This high forecast also agrees

best with growth rates used by KYTC to generate future traffic volumes for the annual submittal of the HPMS file. The rates used most recently to develop 20-year projections of 2003 interstate traffic volumes were 3.35 percent per year for rural segments and 3.00 percent per year for urban segments.

In assessing the other two methodologies, it is interesting to note that the CTS procedure produces overall results that are approximately half-way between the two trendlines. This approach has fallen out of favor over the last several years with KYTC planners, but it certainly appears to give very reasonable values for the interstate routes examined. The SWM is undoubtedly the most sophisticated procedure, and it produces results here that are in the lower end of the range. But, it should be noted that such models are known by practitioners to sometimes produce forecasts that are too low because they do not account very well for the increases in travel propensity (VMT/person) that have been observed over the last several years.

Given that arguments can be made in favor of all four of the forecasting methodologies and that there is no clear “winner” (or “loser”) among them, it was decided that the most reasonable approach would be to utilize the average growth rate for each segment as the most appropriate means for forecasting future traffic volumes.

Therefore, the average growth rates, shown in the right-most column of Table 5, were used to calculate design year traffic conditions for the year 2030. These volumes were used to estimate recurring and non-recurring delay and to project crash trends for future years.

## **5.2 OPERATIONAL ANALYSIS RESULTS**

### **5.2.1 Recurring Congestion**

As indicated above, LOS analysis was conducted for each study period for the 2003 and 2030 traffic demand under the existing roadway configuration. Figures 10 and 11 summarize LOS by analysis period under 2003 and 2030 traffic demand. Figures 12 and 13 summarize peak hour LOS by rural/urban designations and number of lanes for both years. Figures 14 and 15 provide a map showing 2003 and 2030 peak hour LOS by highway section.

As can be seen from the figures, all sections of interstate operate at LOS A during the overnight period for both existing and future traffic demands, and most sections operate at LOS A or B during the off-peak period. However, 10 miles of interstate are shown to operate at LOS C during the off-peak period under 2030 traffic demand, indicating a significant increase in traffic and the potential for spreading of peak period operations in the future. This is further reinforced as over 26 miles of interstate are expected to operate at LOS F during the shoulder period under 2030 demand, compared with no miles under 2003 demand.

Under 2003 conditions, 30 miles of interstate were shown to operate at LOS F during the peak period, the majority on urban interstate sections. However, due to the significant increase in projected traffic volumes for 2030, approximately 390 miles of interstate are expected to operate at LOS F, of which 45 percent are on rural interstates.

Figure 10: Miles of Roadway by LOS and Study Period (2003)

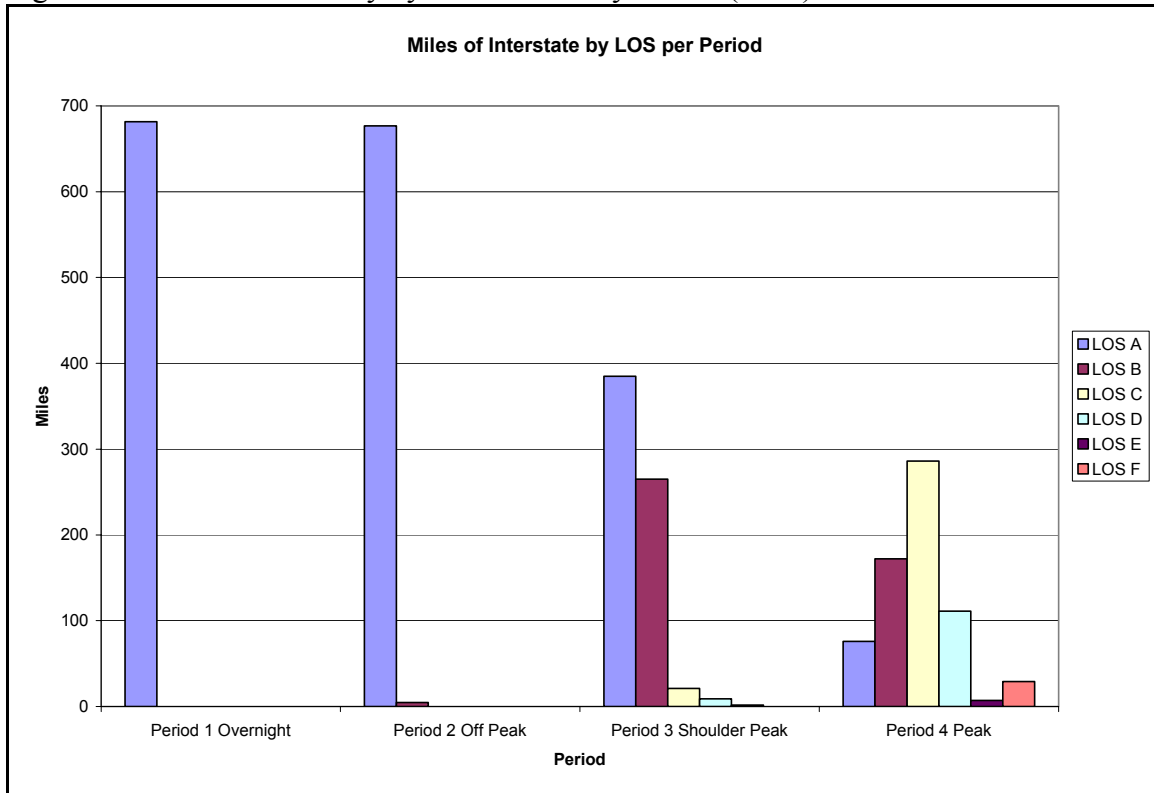


Figure 11: Miles of Roadway by Peak Hour LOS and Rural/Urban Designation(2003)

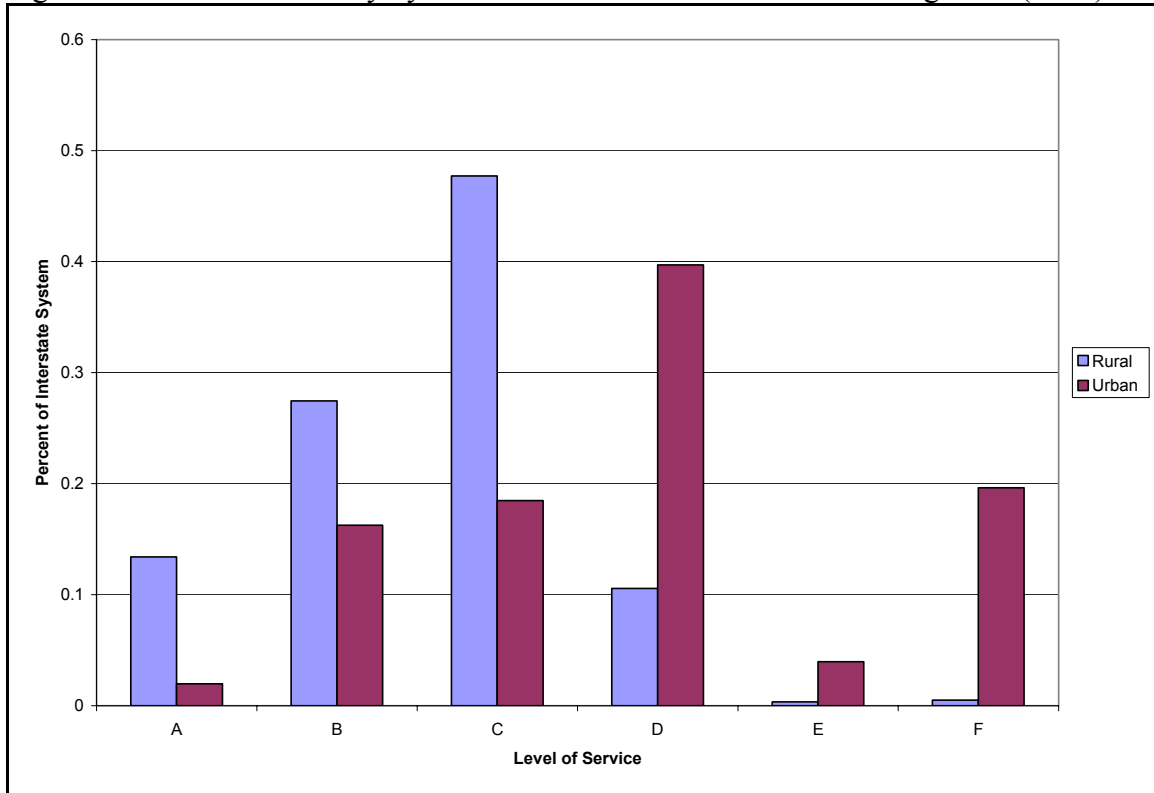


Figure 12: Miles of Roadway by LOS and Study Period (2030)

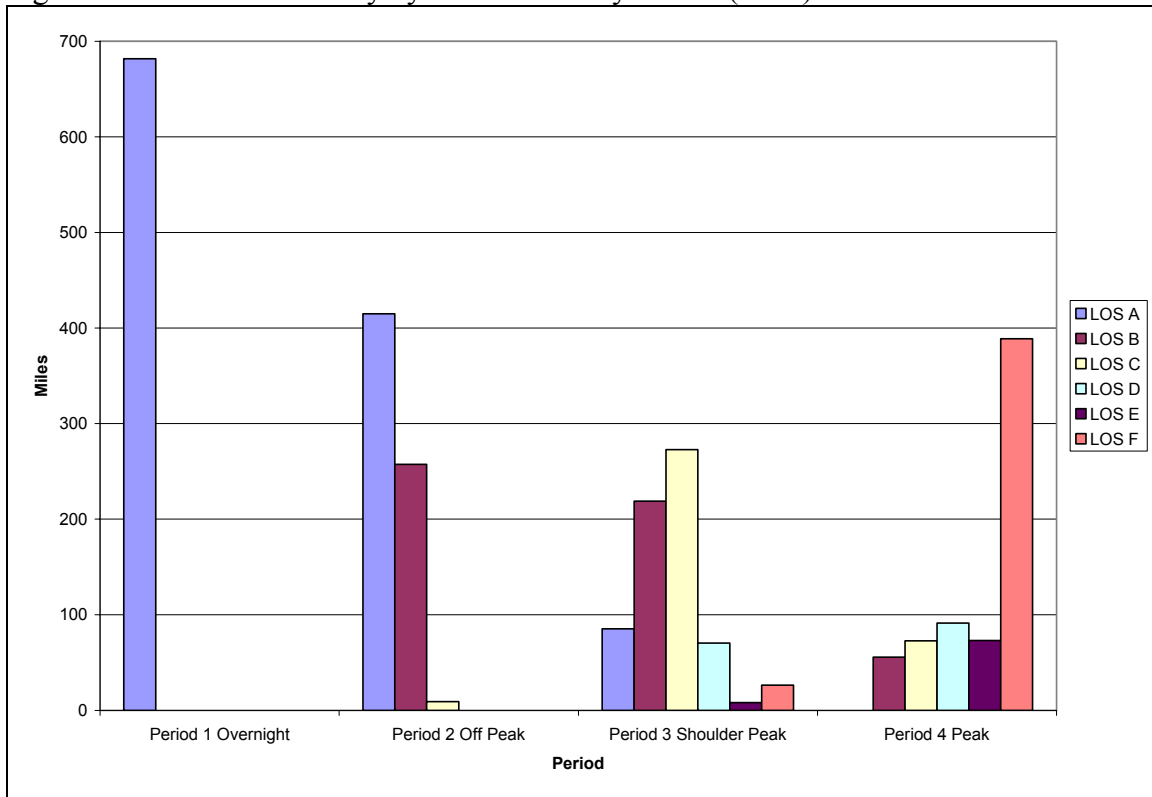


Figure 13: Miles of Roadway by Peak Hour LOS and Rural/Urban Designation(2030)

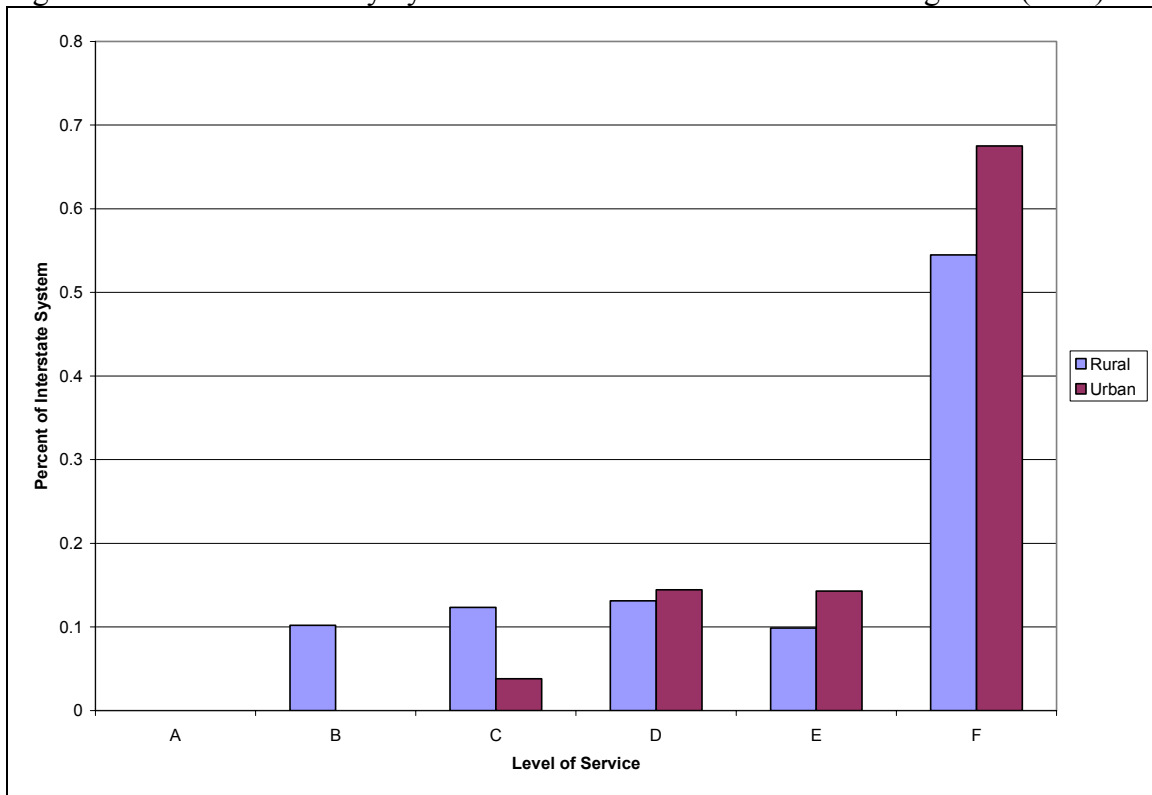


Figure 14: 2003 Peak Hour LOS Analysis



Figure 15: 2030 Peak Hour LOS Analysis

Based upon the capacity analysis, operating speeds were estimated for each period by section. As is expected from the LOS analysis, over 99.9 percent of all delay is experienced in the peak period. Moreover, even though rural interstates account for over 80 percent of the total mileage and 60 percent of the VMT on the study interstate system, delay on rural interstates accounts for less than one percent of total recurring delay.

Table 6 shows total delay for urban and rural sections by number of lanes for 2003 conditions and Table 7 summarizes total delay for 2030 conditions. Four-lane and six-lane urban facilities are shown to have significantly higher delay as compared to 8-lane urban sections and all rural sections.

Table 6: 2003 Total Annual Recurring Delay (Million vehicle-hours)

|              | <b>4 Lanes</b> | <b>6 Lanes</b> | <b>8 Lanes</b> |
|--------------|----------------|----------------|----------------|
| <b>Rural</b> | 0.3            | 0.1            | N/A            |
| <b>Urban</b> | 7.4            | 17.8           | 0.1            |

Table 7: 2030 Total Annual Recurring Delay (veh-hrs)

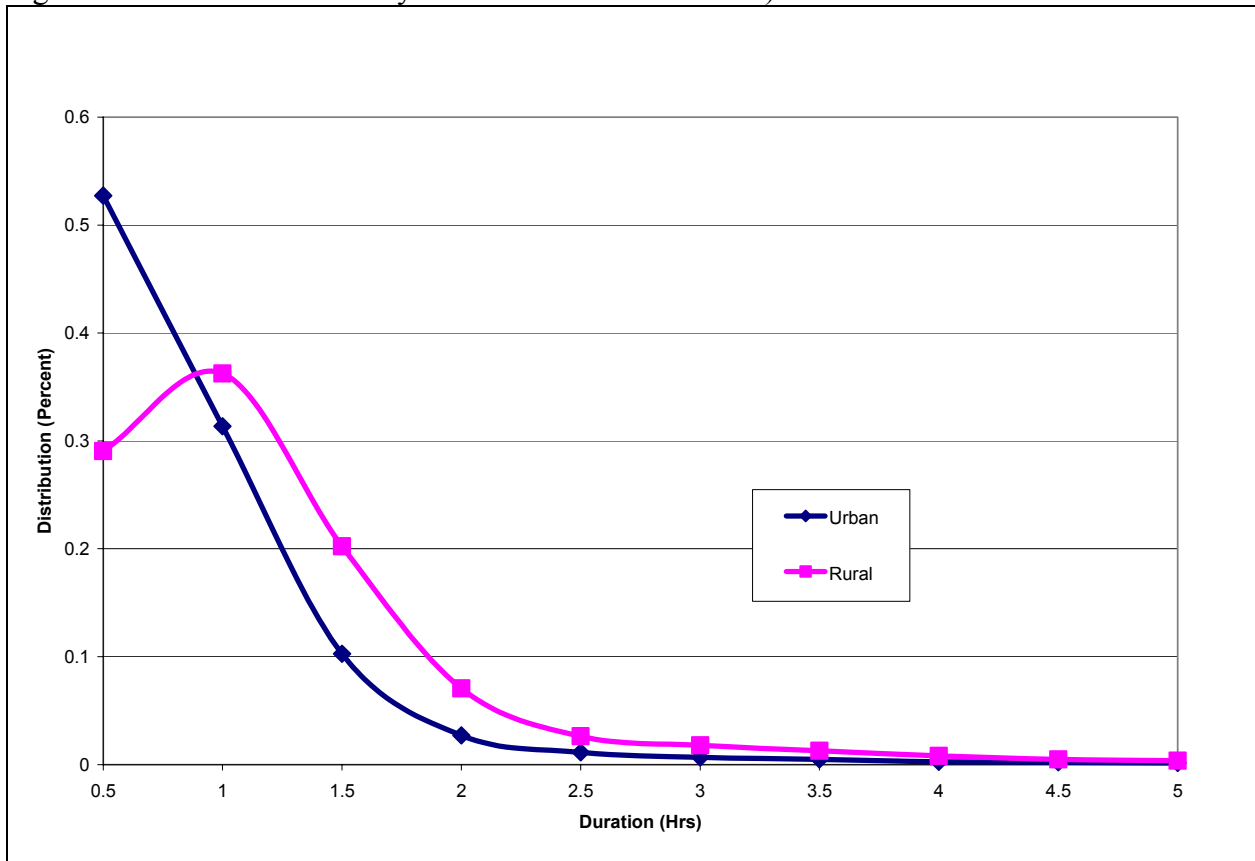
|              | <b>4 Lanes</b> | <b>6 Lanes</b> | <b>8 Lanes</b> |
|--------------|----------------|----------------|----------------|
| <b>Rural</b> | 91.2           | 24.1           | N/A            |
| <b>Urban</b> | 67.4           | 110.7          | 28.2           |

As expected from the LOS analysis, recurring traffic delay under 2030 traffic demand is expected to significantly increase from 26 million veh-hrs annually under 2003 demand to 321 million veh-hrs under 2030 demand. Recurring delay is also expected to spread from the urban centers onto existing rural sections, with the rural interstate network accounting for 35 percent of all recurring delay under 2030 demand volumes.

### 5.2.2 Non-Recurring Congestion Results

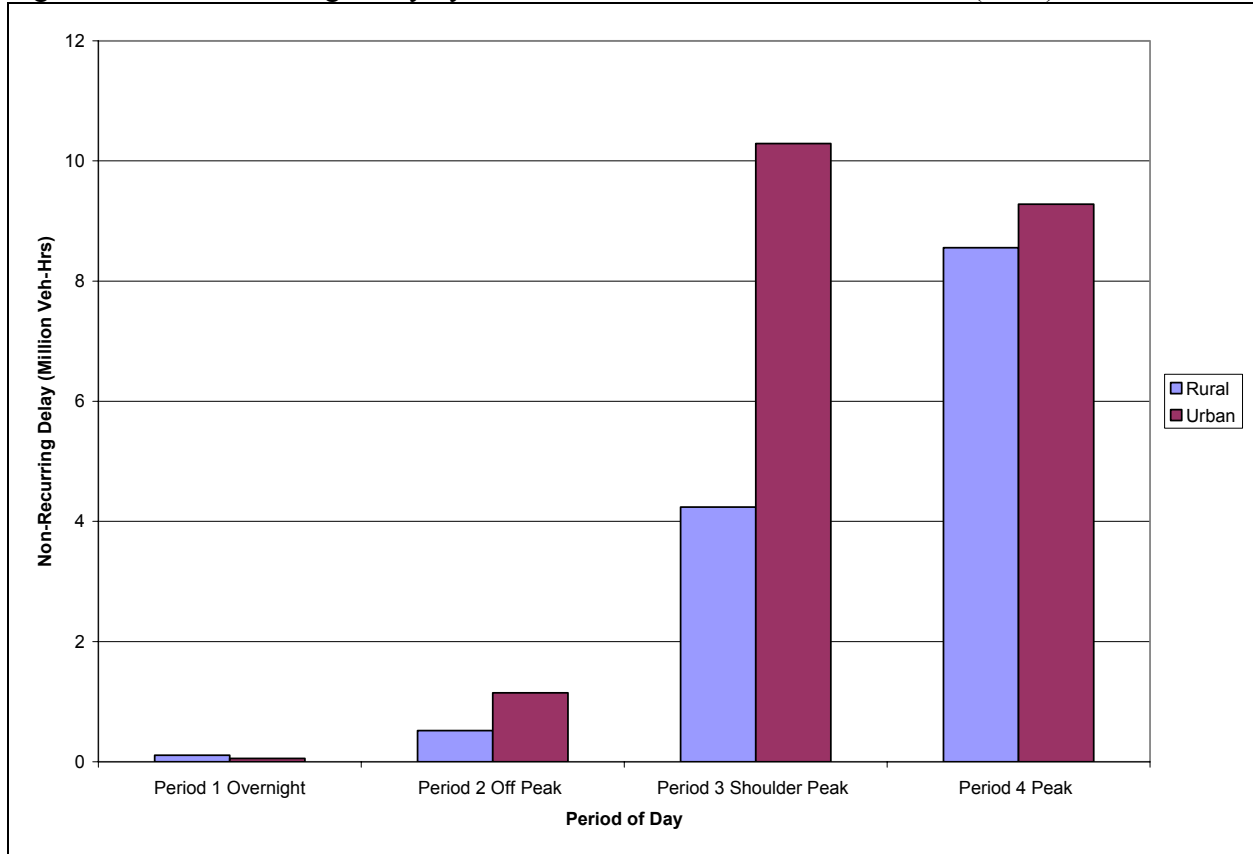
Examination of incident duration indicates that duration is consistent across all lane configurations and there is no significant difference in duration based on period of day. However, significant variation was found between urban and rural classifications. This is shown in Figure 16. Average incident duration for urban and rural interstates was calculated as 0.76 hrs and 1.12 hrs, respectively. The longer duration of incidents on rural segments of the Interstate System is most likely associated with potentially longer response times by emergency personnel due to availability of resources and access to the rural interstate system.

Figure 16: Incident Duration by Rural/Urban Classification)



As stated above, non-recurring congestion and delay caused by crashes was estimated on each study interstate route. Figure 17 summarizes non-recurring delay by period and urban/rural classification.

Figure 17: Non-Recurring Delay by Period and Rural/Urban Classification (2003)



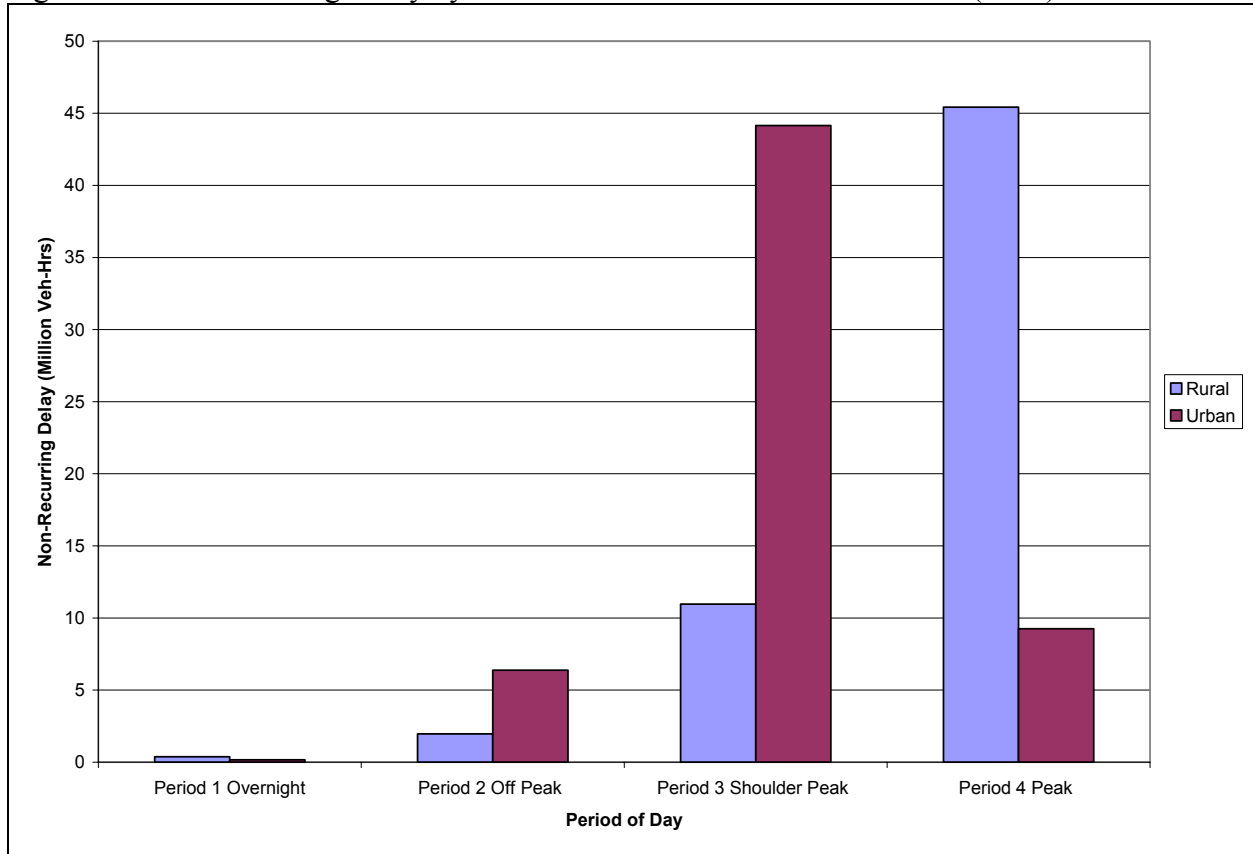
When examined by period of day, over 40 percent of non-recurring congestion occurs during the shoulder period, compared to less than one percent of recurring congestion. This is due to the fact that many sections of roadway are operating at or near capacity during the shoulder period and can be significantly impacted by minor losses of capacity, such as closure of one-lane. During the off peak period and overnight periods, minor capacity losses could have little or no impact on traffic flow and therefore, off peak non-recurring congestion is relatively minor, less than 3 percent of total delay. Non-recurring congestion during the peak hour can significantly impact peak hour operations causing failure of the Interstate System that is already operating at or below an acceptable LOS. Non-Recurring congestion during the peak hour accounts for over 50 percent of non-recurring delay.

Also of significance is the fact that under 2003 traffic volumes, rural interstates are shown to account for almost 40 percent of non-recurring delay, compared to less 0.01 percent of recurring delay.

Figure 18 shows the estimated non-recurring congestion for urban and rural interstate under projected 2030 traffic demand. As can be seen from the figure, non-recurring delay is anticipated to significantly increase, especially in urban areas during the shoulder period. Rural

interstates are also expected to contribute a significantly higher portion of peak period delay compared to existing conditions.

Figure 18: Non-Recurring Delay by Period and Rural/Urban Classification (2030)

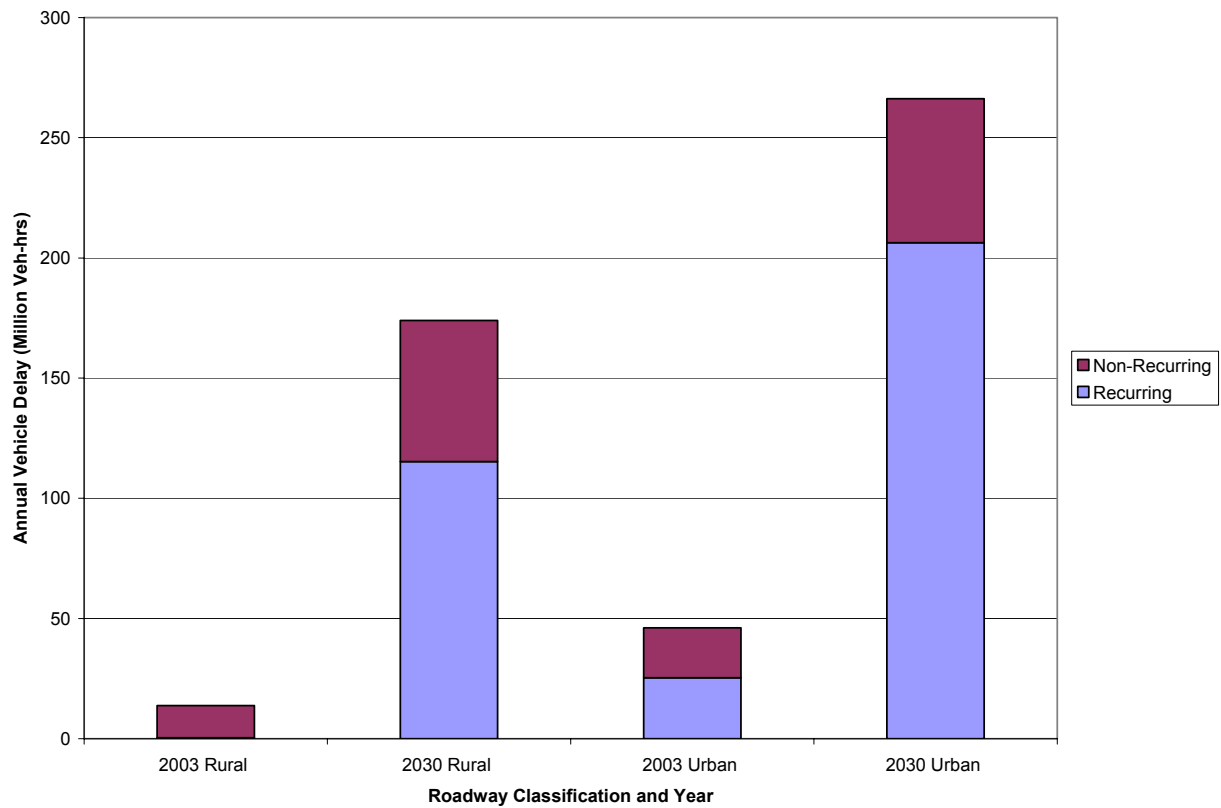


*Note 1: Urban Peak Hour Non-recurring delay cannot be estimated using described methodologies, as all sections are operating over capacity under normal operations and the effect of additional lane closures cannot be estimated.*

### 5.2.3 Interstate Delay

Figure 19 summarizes the total estimated delay (recurring and non-recurring) for rural and urban interstates. As can be seen from the figure, non-recurring delay is shown to provide significantly higher total delays compared to recurring congestion for both the existing and future conditions.

Figure 19: Annual Non-Recurring and Recurring Congestion (Urban and Rural Interstates)



*Note 1: Urban Peak Hour Non-recurring delay cannot be estimated using described methodologies, as all sections are operating over capacity under normal operations and the effect of lane closures cannot be estimated.*

The Federal Highway Administration estimates that non-recurring delay accounts for approximately 50 percent of total delay on the interstate system (17). When accounting for the assumptions and approximations in the methodologies used to estimate recurring and non-recurring delay, the delay analysis presented above is consistent with these findings for the urban section of interstate highways. However, non-recurring delay is shown to be a much more significant contributor of delay on rural interstate sections.

Of primary concern surrounding non-recurring delay is that due to the nature of incidents, this delay is unexpected and not planned. Therefore, non-recurring congestion can have further reaching impacts including lost work productivity, late shipments etc, as it cannot be planned or accounted for as can be done for recurring peak hour congestion. Moreover, alternative bypass routes are typically not readily available on the rural interstate system, where 40 percent of all non-recurring congestion occurs. This analysis demonstrates the potential need for capacity improvements on rural sections to alleviate this non-recurring delay, in addition to urban sections that receive the majority of concentrated capacity improvements.

## 5.3 SAFETY ANALYSIS

### 5.3.1 Crash Rates (Existing Conditions)

#### 5.3.1.1 Overall Crash Rates – Kentucky Compared to the Overall U.S. Rates

Interstates are relatively safe roadways as compared to other roadways in Kentucky. The overall crash rate on rural interstates in Kentucky for the period 1999 through 2003 was 51 crashes per 100 million vehicle miles traveled (MVM) (10). This compares to a crash rate of 124 crashes per 100 MVM for other rural, non-interstate or parkway four-lane divided roadways, and 245 crashes per 100 MVM for rural two-lane roads. Urban interstates had a crash rate of 93 crashes per 100 MVM for the same time period, as compared to a crash rate of 292 for other urban four-lane divided roadways.

Fatal crash rates are available for all states and the level of safety for interstates in Kentucky can be compared to all other interstates in the United States. These data from the 2001 through 2003 Highways Statistics reports indicate that the fatal crash rates for Kentucky are consistently less than the overall U.S. rates (7, 8, 9). The data as presented in Table 8 show the overall fatality crash rate in Kentucky to be 0.69 fatalities per 100 MVM as compared to 0.82 for the entire United States. The difference is even greater when comparing only rural interstates where the rate is 0.86 fatalities per 100 MVM in Kentucky as compared in to a U.S. rate of 1.17.

Table 8. Interstate Fatality Crash Rates in Kentucky as Compared to the United States

|                 | <b>Rural Crash Rate<br/>(per 100 MVM)</b> | <b>Urban Crash Rate<br/>(per 100 MVM)</b> | <b>Total Crash Rate<br/>(per 100 MVM)</b> |
|-----------------|---|---|---|
| <i>Kentucky</i> | 0.86                                      | 0.51                                      | 0.69                                      |
| <i>All U.S.</i> | 1.17                                      | 0.58                                      | 0.82                                      |

#### 5.3.1.2. Overall Crash Rates on Kentucky Interstates

Numbers of crashes were compiled and crash rates were calculated for all vehicles using the period of July 1, 2001 through June 30, 2004. This three-year summary of crashes and crash rates for each of the interstates in Kentucky is compiled in Table 9. Included were the five cross-state or generally rural interstates (I-24, I-64, I-65, I-71, and I-75), and the four generally urban bypass-type interstates (I-264, I-265, I-275, and I-471). The data in Table 9 show that the highest overall rates were on I-471 and I-264, with the lowest rates on I-265 and I-24. Fatal crash rates were highest on I-71 and I-65, with the lowest fatal rates on I-264 and I-265.

Table 9. Summary of Crashes and Crash Rates for Kentucky Interstates (July 2001 through June 2004)

| Route        | All Crashes   |               |               | Overall Crash Rate<br>(Crashes/100 MVM) |            |           | Fatal Crashes |           |            | Fatal Crash Rates<br>(Crashes/100 MVM) |             |             |
|--------------|---------------|---------------|---------------|---|------------|-----------|---------------|-----------|------------|--|-------------|-------------|
|              | Rural         | Urban         | Total         | Rural                                   | Urban      | Total     | Rural         | Urban     | Total      | Rural                                  | Urban       | Total       |
| <i>I-24</i>  | 781           | 446           | 1,227         | 47                                      | 75         | 54        | 8             | 2         | 10         | 0.48                                   | 0.33        | 0.44        |
| <i>I-64</i>  | 2,940         | 2,528         | 5,468         | 60                                      | 116        | 77        | 27            | 8         | 35         | 0.55                                   | 0.37        | 0.49        |
| <i>I-65</i>  | 2,341         | 3,930         | 6,271         | 52                                      | 121        | 81        | 48            | 15        | 63         | 1.07                                   | 0.46        | 0.81        |
| <i>I-71</i>  | 1,003         | 1,067         | 2,070         | 58                                      | 79         | 67        | 18            | 10        | 28         | 1.04                                   | 0.74        | 0.91        |
| <i>I-75</i>  | 3,823         | 4,225         | 8,048         | 60                                      | 102        | 77        | 43            | 18        | 61         | 0.68                                   | 0.44        | 0.58        |
| <i>I-264</i> | N/A           | 3,562         | 3,562         | N/A                                     | 134        | 134       | N/A           | 8         | 8          | N/A                                    | 0.30        | 0.30        |
| <i>I-265</i> | N/A           | 841           | 841           | N/A                                     | 48         | 48        | N/A           | 7         | 7          | N/A                                    | 0.41        | 0.41        |
| <i>I-275</i> | 146           | 1,710         | 1,856         | 74                                      | 108        | 104       | 1             | 9         | 10         | 0.51                                   | 0.57        | 0.56        |
| <i>I-471</i> | N/A           | 735           | 735           | N/A                                     | 142        | 142       | N/A           | 3         | 3          | N/A                                    | 0.58        | 0.58        |
| <b>Total</b> | <b>11,034</b> | <b>19,044</b> | <b>30,078</b> | <b>57</b>                               | <b>106</b> | <b>80</b> | <b>145</b>    | <b>80</b> | <b>225</b> | <b>0.75</b>                            | <b>0.45</b> | <b>0.60</b> |

### 5.3.1.3 Truck Crash Rates on Kentucky Interstates

Numbers of crashes and crash rates for trucks (commercial vehicles with a registered weight of greater than 10,000 pounds) were also compiled and presented in Table 10. Results show that the highest overall rates were on I-264 and I-275, with the lowest rates on I-24, I-265 and I-471. These routes with highest and lowest rates for commercial vehicles were similar to those for all vehicles. The exception was I-471, which was one of the two routes with highest overall rates, with this route replaced with I-275 as one of the two routes with highest commercial vehicle rates. Fatal Crash Rates were highest on I-275 and I-71.



Table 10. Summary of Truck Crash Rates for Kentucky Interstates

| Route        | All Crashes  |              |              | Overall Crash Rate<br>(Crashes/100 MVM) |           |           | Fatal Crashes |           |           | Fatal Crash Rates<br>(Crashes/100 MVM) |             |             |
|--------------|--------------|--------------|--------------|---|-----------|-----------|---------------|-----------|-----------|--|-------------|-------------|
|              | Rural        | Urban        | Total        | Rural                                   | Urban     | Total     | Rural         | Urban     | Total     | Rural                                  | Urban       | Total       |
| I-24         | 172          | 60           | 232          | 33                                      | 46        | 36        | 5             | 0         | 5         | 0.96                                   | 0.00        | 0.77        |
| I-64         | 514          | 304          | 818          | 45                                      | 117       | 59        | 9             | 1         | 10        | 0.79                                   | 0.39        | 0.72        |
| I-65         | 749          | 640          | 1,389        | 43                                      | 108       | 60        | 18            | 4         | 22        | 1.04                                   | 0.67        | 0.95        |
| I-71         | 294          | 191          | 485          | 52                                      | 91        | 63        | 10            | 5         | 15        | 1.78                                   | 2.39        | 1.94        |
| I-75         | 847          | 992          | 1,839        | 45                                      | 107       | 65        | 13            | 10        | 23        | 0.68                                   | 1.08        | 0.81        |
| I-264        | N/A          | 342          | 342          | N/A                                     | 120       | 120       | N/A           | 0         | 0         | N/A                                    | 0.00        | 0.00        |
| I-265        | N/A          | 83           | 83           | N/A                                     | 45        | 45        | N/A           | 2         | 2         | N/A                                    | 1.07        | 1.07        |
| I-275        | 36           | 164          | 200          | 194                                     | 88        | 98        | 1             | 3         | 4         | 5.38                                   | 1.62        | 1.96        |
| I-471        | N/A          | 18           | 18           | N/A                                     | 51        | 51        | N/A           | 0         | 0         | N/A                                    | 0.00        | 0.00        |
| <b>Total</b> | <b>2,612</b> | <b>2,794</b> | <b>5,406</b> | <b>45</b>                               | <b>99</b> | <b>62</b> | <b>56</b>     | <b>25</b> | <b>81</b> | <b>0.96</b>                            | <b>0.89</b> | <b>0.93</b> |

#### 5.3.1.4 Overall Crash Rates on Kentucky Interstates by Number of Lanes

A special focus of this analysis of interstate highway safety in Kentucky was to determine whether there is a difference in crash rates as a function of number of lanes. Presented in Table 11 is a summary of crash rates for rural and urban sections of 4, 6, and 8-lane interstates in Kentucky. The analysis included 759 miles of interstate representing the 4, 6, and 8-lane sections (there were four miles of interstate listed with seven lanes and these sections were omitted from the analysis). Overall crash rates show the 4-lane and 6-lane sections of rural interstates had the same rate of 57 crashes per 100 MVM (there were no rural 8-lane sections). For urban sections, the overall rate was basically the same for 4-lane and 6-lane sections (101 and 102 crashes per 100 MVM, respectively). However, the 8-lane sections (representing 24 miles) had a rate of 86 crashes per 100 MVM (approximately 15 percent less than the 4-lane and 6-lane sections). The rates for crashes involving either an injury or a fatality were 10 percent less on 6-lane rural interstates as compared to 4-lane sections. However, there was a slight increase in injury /fatal rates when comparing urban 6-lane sections with urban 4-lane sections. When comparing urban 8-lane sections with urban 6-lane sections, there was a decrease of approximately 11 percent. It appears that crash rates generally improve when more lanes are available, especially for crashes involving injuries or fatalities.

Table 11. Summary of Overall Crash Rates by Number of Lanes for Kentucky Interstates

| Number of Lanes | Miles | Rural Crash Rate<br>(per 100 MVM) | Urban Crash Rate<br>(per 100 MVM) | Rural Injury/Fatal<br>Crash Rate<br>(per 100 MVM) | Urban Injury/Fatal<br>Crash Rate<br>(per 100 MVM) |
|-----------------|-------|-----------------------------------|-----------------------------------|---|---|
| 4               | 543   | 57                                | 101                               | 15.2  | 21.1  |
| 6               | 192   | 57                                | 102                               | 13.7  | 21.7  |
| 8               | 24    | N/A                               | 86                                | N/A   | 19.3  |

### 5.3.1.5 Commercial Vehicle Crash Rates on Kentucky Interstates by Number of Lanes

Presented in Table 12 is a summary of commercial vehicle (truck) crash rates on Kentucky interstates by number of lanes. This table shows a pattern of decreasing rates (overall and injury/fatal) with increased number of lanes when comparing rural 4-lane and 6-lane sections. For all rural crashes, the crash rate is 16 percent less on 6-lane sections as compared to 4-lane sections and 25 percent less for rural injury/fatal crashes. However, when comparing urban 4-lane, 6-lane, and 8-lane sections, there is a pattern of increasing crash rates with increasing number of lanes for all crashes and injury/fatal crashes.

Table 12. Summary of Truck Crash Rates by Number of Lanes for Kentucky Interstates

| Number of Lanes | Miles | Rural Crash Rate (per 100 MVM) | Urban Crash Rate (per 100 MVM) | Rural Injury/Fatal Crash Rate (per 100 MVM) | Urban Injury/Fatal Crash Rate (per 100 MVM) |
|-----------------|-------|--------------------------------|--------------------------------|---|---|
| 4               | 543   | 50                             | 46                             | 12.5  | 10.3  |
| 6               | 192   | 42                             | 66                             | 9.4   | 14.5  |
| 8               | 24    | N/A                            | 84                             | N/A   | 17.2  |

### 5.3.1.6 Critical Rate Analysis

The actual and critical crash rates were determined for each HPMS section, and a critical rate factor (CRF) was calculated. Critical rates for all crashes and for crashes involving commercial vehicles were calculated. Sections with a CRF over 1.0 are shown in Table 13 (all crashes) and Table 14 (commercial vehicle crashes). Maps showing these locations are presented in Figures 20 and 21. There were 48 sections (165 miles) identified as having a critical rate factor greater than 1.0. There were 26 sections (93 miles) identified as having a critical commercial vehicle rate factor greater than 1.0. Several of the sections with the highest CRFs are in Jefferson County. Four of the five sections with the highest CRFs for all crashes were on I-264.

Table 13: Sections with Critical Rate Factors  $> 1.0$  (All Crashes)

Table 14: Sections with Critical Rate Factors > 1.0 (Commercial Vehicle Crashes)

Figure 20: CRF by Section (All Crashes)

Figure 21: CRF by Section (Commercial Vehicle Crashes)

### 5.3.1.7 Crash Rate and Operational Performance Analysis

A primary objective of this study was to examine the relationship between crash rates and the operational characteristics of the roadway section. The hypothesis of this analysis was that crash rates would be affected by the density, operating speed, and freedom of mobility within the traffic stream. Therefore, this analysis could provide additional insight into interstate crash patterns. Tables 15 and 16 provide a summary of crash rates by peak hour LOS and peak hour V/C ratios. As can be seen from this table, a minor reduction in crash rates is present for sections having a LOS B or C. This may be indicative of traffic conditions that limit mobility to a point where driver attention is improved, while not overloading the demands on the driver. However, as a general trend, crash rates increase with degradation of LOS and V/C.

Table 15: Summary of Crash Rates by Peak Hour LOS

| <b>LOS</b>   | <b>4 Lanes</b> | <b>6 Lanes</b> | <b>8 Lanes</b> | <b>Total</b> |
|--------------|----------------|----------------|----------------|--------------|
| <i>LOS A</i> | 64.02          | N/A            | 41.10          | 62.05        |
| <i>LOS B</i> | 48.83          | 71.49          | N/A            | 55.30        |
| <i>LOS C</i> | 60.56          | 59.09          | 90.36          | 60.51        |
| <i>LOS D</i> | 69.30          | 74.27          | 49.43          | 68.45        |
| <i>LOS E</i> | 70.95          | N/A            | 101.90         | 98.24        |
| <i>LOS F</i> | 136.54         | 148.32         | N/A            | 145.42       |
| <i>Total</i> | 64.59          | 87.59          | 74.81          |              |

Table 16: Summary of Crash Rates by Peak Hour V/C Ratio

| <b>V/C Ratio</b> | <b>4 Lanes</b> | <b>6 Lanes</b> | <b>8 Lanes</b> | <b>Total</b> |
|------------------|----------------|----------------|----------------|--------------|
| <i>&lt;0.4</i>   | 53.77          | N/A            | 41.10          | 51.66        |
| <i>0.4-0.8</i>   | 57.10          | 80.28          | N/A            | 63.49        |
| <i>&gt;0.8</i>   | 67.36          | 88.76          | 76.90          | 76.42        |
| <i>Total</i>     | 64.59          | 87.59          | 74.81          |              |

Commercial vehicle crash rates were also examined with respect to LOS and V/C ratios. Tables 17 and 18 summarize these rates. A similar pattern as exhibited for overall crash rates is also seen with respect truck crashes, demonstrating an increase in crash rate with degradation of LOS and V/C.

Table 17: Summary of Commercial Vehicle Crash Rates by Peak hour LOS

| <b>LOS</b>   | <b>4 Lanes</b> | <b>6 Lanes</b> | <b>8 Lanes</b> | <b>Total</b> |
|--------------|----------------|----------------|----------------|--------------|
| <i>LOS A</i> | 11.92          | N/A            | 10.49          | 11.79        |
| <i>LOS B</i> | 11.56          | 14.75          | N/A            | 12.47        |
| <i>LOS C</i> | 14.28          | 14.27          | 27.57          | 14.49        |
| <i>LOS D</i> | 13.45          | 13.72          | 13.68          | 13.56        |
| <i>LOS E</i> | 11.98          | N/A            | 23.56          | 22.19        |
| <i>LOS F</i> | 18.24          | 22.81          | N/A            | 21.68        |
| <i>Total</i> | 13.57          | 16.51          | 18.98          |              |

Table 18: Summary of Commercial Vehicle Crash Rates by Peak hour V/C Ratio

| <b>V/C Ratio</b> | <b>4 Lanes</b> | <b>6 Lanes</b> | <b>8 Lanes</b> | <b>Total</b> |
|------------------|----------------|----------------|----------------|--------------|
| <i>&lt;0.4</i>   | 9.78           | N/A            | 10.49          | 9.90         |
| <i>0.4-0.8</i>   | 11.20          | 16.70          | N/A            | 12.71        |
| <i>&gt;0.8</i>   | 14.46          | 16.48          | 19.51          | 15.63        |
| <b>Total</b>     | <b>13.57</b>   | <b>16.51</b>   | <b>18.98</b>   | <b>14.98</b> |

While not a primary objective of this study, one of the major factors found to influence crash rates was interchange density. Table 19 summarizes overall crash rates by number of lanes and interchange density. A definite trend is shown in which crash rates increase with an increase interchange density. However, an anomaly is also present, in that mid-range interchange densities (0.5-1.0 interchanges per mile) show a significant decrease in crash rates compared to low and high interchange densities. This may be indicative of mid-range interchange densities providing enough stimuli to drivers to make them attentive, while not overloading the driver with weaving and merging maneuvers. This factor may be similar to the minor reduction apparent with LOS B or C operations as examined above.

Table 19: Summary of Crash Rates by Number of Lanes and Interchange Density

| <b>Interchange Density</b> | <b>4 Lanes</b> | <b>6 Lanes</b> | <b>8 Lanes</b> | <b>Total</b> |
|----------------------------|----------------|----------------|----------------|--------------|
| <i>0</i>                   | 64.10          | 92.71          | 76.90          | 81.91        |
| <i>0-0.5</i>               | 66.67          | 86.41          | 41.10          | 70.15        |
| <i>0.5-1.0</i>             | 50.89          | 61.68          | N/A            | 55.05        |
| <i>&gt;1.0</i>             | 113.53         | N/A            | N/A            | 113.53       |
| <b>Total</b>               | <b>64.59</b>   | <b>87.59</b>   | <b>74.81</b>   |              |



### 5.3.2 Crash Rates (Alternative Analysis)

A multi-variate regression model was developed for overall crash patterns on the study routes. This model was used to determine the predicted change in rates due to changes in lane configurations for the Alternative Analysis. Table 20 summarizes the variables, coefficients, and measures of model fit ( $R^2$  values).

Table 20: Crash Rate Regression Model Variables

| Variable                                 | Description   | Average Value ( $\mu$ ) | Standard Deviation ( $\sigma$ ) | Coefficient (C) | P-Value | $\Delta^{1,2}$ |
|--|---|-------------------------|---------------------------------|-----------------|---------|----------------|
| <b>Regression Analysis</b>               |   |                         |                                 |                 |         |                |
| <b>Constant</b>                          | <i>Constant</i>   | NA                      | NA                              | 51.474          | NA      | 49.71          |
| <b>(Interchange Density)<sup>2</sup></b> | <i>Square of Interchange Density</i>  | 0.24                    | 0.26                            | 66.05           | 0.00    | 17.17          |
| <b>(ADT Per Lane)<sup>2</sup></b>        | <i>Square of (ADT / No. of Lanes) / 100000</i>                                  | 1023.24                 | 1277.234                        | 0.010587        | 0.00    | 13.52          |
| <b>IC Density Mid Range (0.5-1.06)</b>   | <i>Interchange Density between 0.56 and 1.06 interchanges per mile (Binary)</i> | NA                      | 1                               | -30.14          | 0.02    | -30.14         |
| <b>Urban</b>                             | <i>Urban Functional Classification (Binary)</i>                                 | NA                      | 1                               | 18.41           | 0.02    | 18.41          |
| <b>R<sup>2</sup></b>                     |   |                         |                                 |                 |         | <b>24.6</b>    |
| <b>R<sup>2</sup>-Adjusted</b>            |   |                         |                                 |                 |         | <b>22.6</b>    |
| <b>Predicted R<sup>2</sup></b>           |   |                         |                                 |                 |         | <b>18.19</b>   |
| <i>Notes</i>                             |   |                         |                                 |                 |         |                |
| 1. $\Delta = C \cdot \sigma$             |   |                         |                                 |                 |         |                |
| 2. $\Delta$ (Binary) = $C \cdot 1$       |   |                         |                                 |                 |         |                |

Model output was compared to measures of fit for traditional crash analysis procedures of applying average crash rates based on urban/rural designations and the number of lanes of the facility (Table 11). This comparison is shown in Table 21.

Table 21: Comparison of Regression Model and Average Values

| Crash Prediction Mode                             | R <sup>2</sup> | R <sup>2</sup> -Adjusted | Predicted R <sup>2</sup> |
|---|----------------|--------------------------|--------------------------|
| <i>Regression Model</i>                           | 24.6           | 22.6                     | 18.19                    |
| <i>Average Rate By No. of Lanes (Urban/Rural)</i> | 11.4           | 9.7                      | 6.23                     |

While the  $R^2$  value of 24.6 percent does not indicate an exact fit of the data points examined, it does indicate that approximately 25 percent of the variation exhibited within the

161 study sections examined can be explained with the four variables included in the model, compared with 11.4% when using average values by number of lanes. The remaining unexplained data may be due to other roadway and environmental factors that are not included in the analysis, such as sun spots, extensive deer populations, etc., and site specific data such as topography, etc, that is not included in the HPMS data set. Moreover, all variables included in the model were shown to have a confidence level of 98 percent or greater that they do impact interstate crash rates, as indicated by the P-Statistic.

Based upon this analysis, the most significant contributors to the total crash rate on the study interstates are the ADT and interchange density. Peak and off-peak periods LOS and V/C ratios were not shown to have a significant influence on crash rates. Based on this analysis, increases in the crash rate shown in Tables 15 and 16, which may be attributed to worsening LOS, would more likely be attributed to an increase in overall ADT and not necessarily representative of the operational conditions.

Commercial vehicle volumes and percentages were also examined in the regression analysis. A statistically significant influence of commercial traffic on crash rates was not found in the analysis.

The general crash rate trend with increasing ADT and increasing density of interchanges is shown in Figures 22 and 23. The exponential nature of these trends is such that small increases in ADT and interchange densities can significantly increase the crash rate on the upper limits of the ADT and interchange density range. As can also be seen from Figure 23, there is a significant decrease in crash rates at the mid range interchange densities, as was evident from Table 19, above.

Figure 22: Effect of ADT on Crash Rate

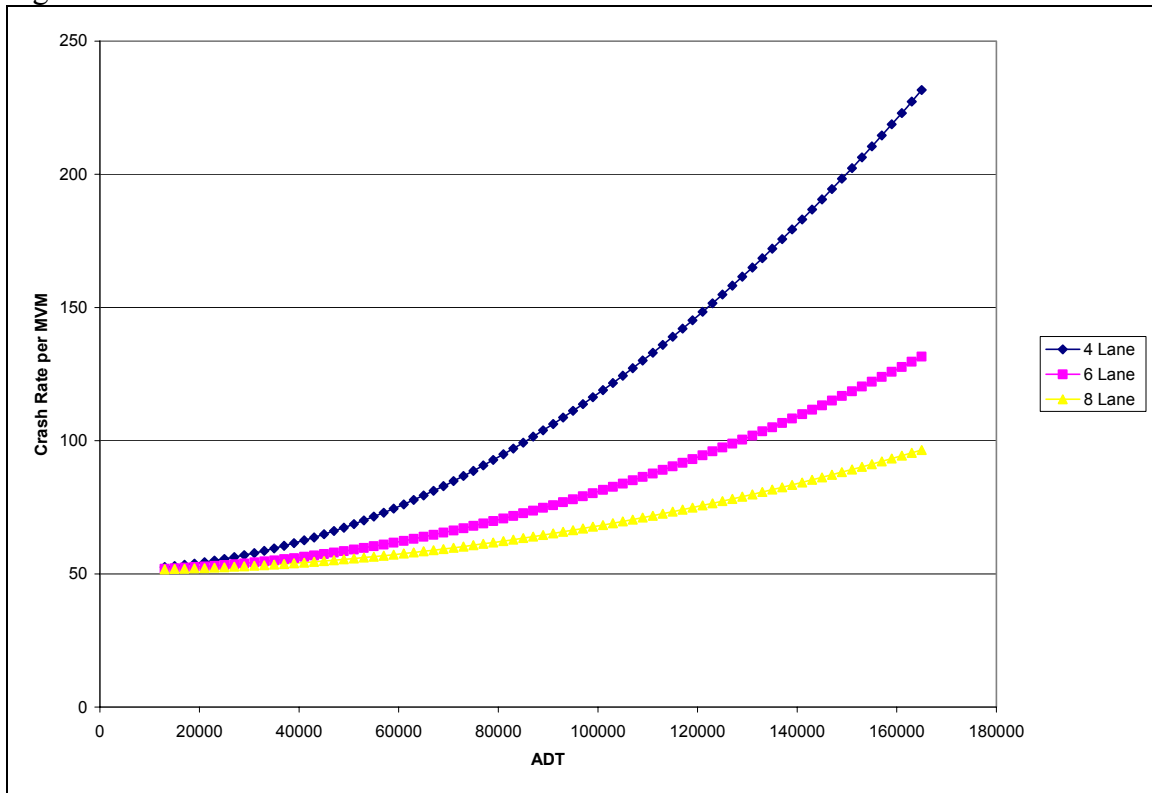
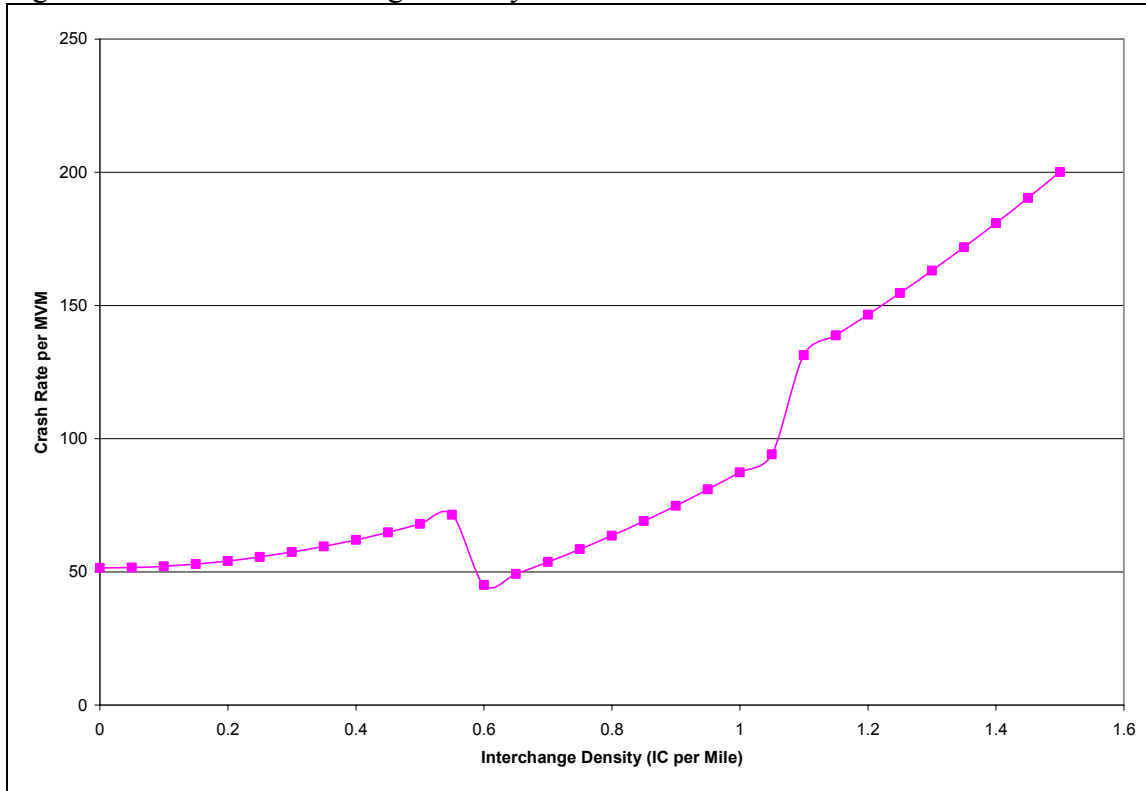


Figure 23: Effect of Interchange Density on Crash Rate



### 5.4 ALTERNATIVE ANALYSIS

Alternative analysis was conducted to compare potential user cost savings between the existing conditions (No Build Alternative) and the Build Alternative. Applying the methodologies described above, annual recurring delay, non-recurring delay and crashes were determined for each HPMS section under existing (2003) and future year (2030) traffic demand for the No Build and Build Alternatives. Table 22 summarizes the recurring delay for both alternatives for the existing and future years (2030). Table 23 summarizes alternative non-recurring delay for the existing and future year. Table 24 summarizes projected annual crashes, for all interstate study sections by number of lanes and alternative.

Table 22: Recurring Delay by Existing No. of Lanes (Veh-hrs)

|                                   | 4 Lane      | 6 Lane      | 8 Lane     |
|-----------------------------------|-------------|-------------|------------|
| <b>Existing Conditions (2003)</b> |             |             |            |
| <i>Existing</i>                   | 13,920,485  | 29,292,709  | 94,644     |
| <i>Alternative</i>                | 72,945      | 241,430     | 94,644     |
| <b>Design Year (2030)</b>         |             |             |            |
| <i>Existing</i>                   | 484,277,538 | 296,474,595 | 78,994,638 |
| <i>Alternative</i>                | 52,955,113  | 134,200,060 | 78,994,638 |

Table 23: Non-Recurring Delay by Existing No. of Lanes and Alternative (Veh-hrs)

|                                  | <b>4 Lane</b> | <b>6 Lane</b> | <b>8 Lane</b> |
|----------------------------------|---------------|---------------|---------------|
| <b>Existing Conditions, 2003</b> |               |               |               |
| <i>Existing</i>                  | 13,128,799    | 11,189,061    | 28,464,660    |
| <i>Alternative</i>               | 6,413,692     | 6,407,260     | 28,464,660    |
| <b>Design Year2030</b>           |               |               |               |
| <i>Existing</i>                  | 83,061,707    | 11,633,383    | 120,227,622   |
| <i>Alternative</i>               | 11,955,458    | 7,201,416     | 120,227,622   |

Table 24: Predicted Annual Crashes by Existing No. of Lanes and Alternative

|                                  | <b>4 Lane</b> | <b>6 Lane</b> | <b>8 Lane</b> |
|----------------------------------|---------------|---------------|---------------|
| <b>Existing Conditions, 2003</b> |               |               |               |
| <i>Existing</i>                  | 4,089         | 3,011         | 614           |
| <i>Alternative</i>               | 3,724         | 2,656         | 614           |
| <b>Design Year2030</b>           |               |               |               |
| <i>Existing</i>                  | 7,386         | 5,335         | 1,099         |
| <i>Alternative</i>               | 6,731         | 4,705         | 1,099         |

Both recurring and non-recurring congestion are expected to be significantly reduced with the implementation of the Build Alternative. This is due to the added capacity for daily traffic demands, as well as additional capacity to more effectively dissipate queues after lane closures due to an incident. Recurring and non-recurring delay is expected to be decreased by 99 percent and 25 percent, respectively under existing traffic demand and by 69 percent and 35 percent under 2030 conditions.. The largest reduction in delay is expected in widening 4 lane facilities to 6 lane facilities for both recurring and non-recurring congestion. There is also a dramatic reduction in recurring delay when expanding facilities from 6 to 8 lanes.

As the Build Alternative will decrease the ADT per lane on improved sections, the crash rate is expected to decrease under the Build Alternative. Tables 26 and 27 show that a more pronounced crash reduction would be expected by widening 6 lane facilities to 8 lane facilities, as compared to widening 4 lane facilities to 6 lane facilities. This is due to the higher ADT served by these facilities that produce a more pronounced difference between crash rates of the two alternatives. These findings are consistent with the average crash rates by number of lanes shown in Table 11.

#### 5.4.2 Benefit Cost Analysis

Benefit cost ratios were developed for each interstate section using the procedures described in section 4.4. Over the 27 year design life, 110 sections were shown to have a B/C ratio greater than 1, indicating a positive return on initial infrastructure costs. Also, 57 sections were shown to have a B/C ratio greater than 2.5. Figure 24 shows those sections with B/C ratios

less than 1, between 1 and 2.5, and those greater than 2.5. Those sections having the ten highest B/C ratios are summarized in Table 25 with LOS and ADT characteristics. Of the top ten sections with the highest B/C ratios, 8 are 4-lane facilities, 7 of which are rural interstates. All sections operate at LOS D, E or F during the peak hour, except for one section which operates at LOS C.

Table 25: HPMS Sections with Highest B/C Ratio

| <b>Route</b> | <b>BMP</b> | <b>EMP</b> | <b>Lanes</b> | <b>ADT</b> | <b>Urban\<br/>Rural</b> | <b>Pk Hr<br/>LOS</b> | <b>B/C Ratio</b> |
|--------------|------------|------------|--------------|------------|-------------------------|----------------------|------------------|
| 65           | 0.000      | 1.980      | 4            | 44,300     | R                       | F                    | 175.7            |
| 75           | 40.837     | 45.901     | 4            | 32,000     | R                       | C                    | 170.1            |
| 65           | 1.980      | 5.979      | 4            | 40,301     | R                       | D                    | 125.8            |
| 64           | 18.888     | 20.765     | 4            | 52,800     | R                       | E                    | 119.8            |
| 64           | 4.533      | 6.303      | 4            | 121,231    | U                       | F                    | 116.7            |
| 64           | 20.765     | 23.974     | 4            | 52,800     | R                       | D                    | 111.3            |
| 64           | 23.974     | 31.842     | 4            | 52,203     | R                       | D                    | 110.9            |
| 75           | 144.443    | 166.263    | 4            | 40,071     | R                       | D                    | 108.1            |
| 75           | 183.312    | 186.347    | 6            | 164,137    | U                       | F                    | 105.6            |
| 75           | 115.226    | 120.792    | 6            | 61,626     | R                       | D                    | 105.6            |

Figure 24: Kentucky Map of B/C Ratios

## 5.5 ADDITIONAL ANALYSIS

In addition to general mixed use capacity improvements, commercial vehicle specific improvements were also examined due to interest in truck-only interstate facilities being examined in other states. Analysis was conducted to determine the number of lanes that would be required to maintain a minimum peak hour LOS D under design year 2030 traffic demand for 1) a mixed use facility and 2) a facility with separated truck and passenger car traffic. A minimum of two lanes in each direction was maintained for passenger car facilities and a minimum of one lane in each direction was maintained for all truck facilities.

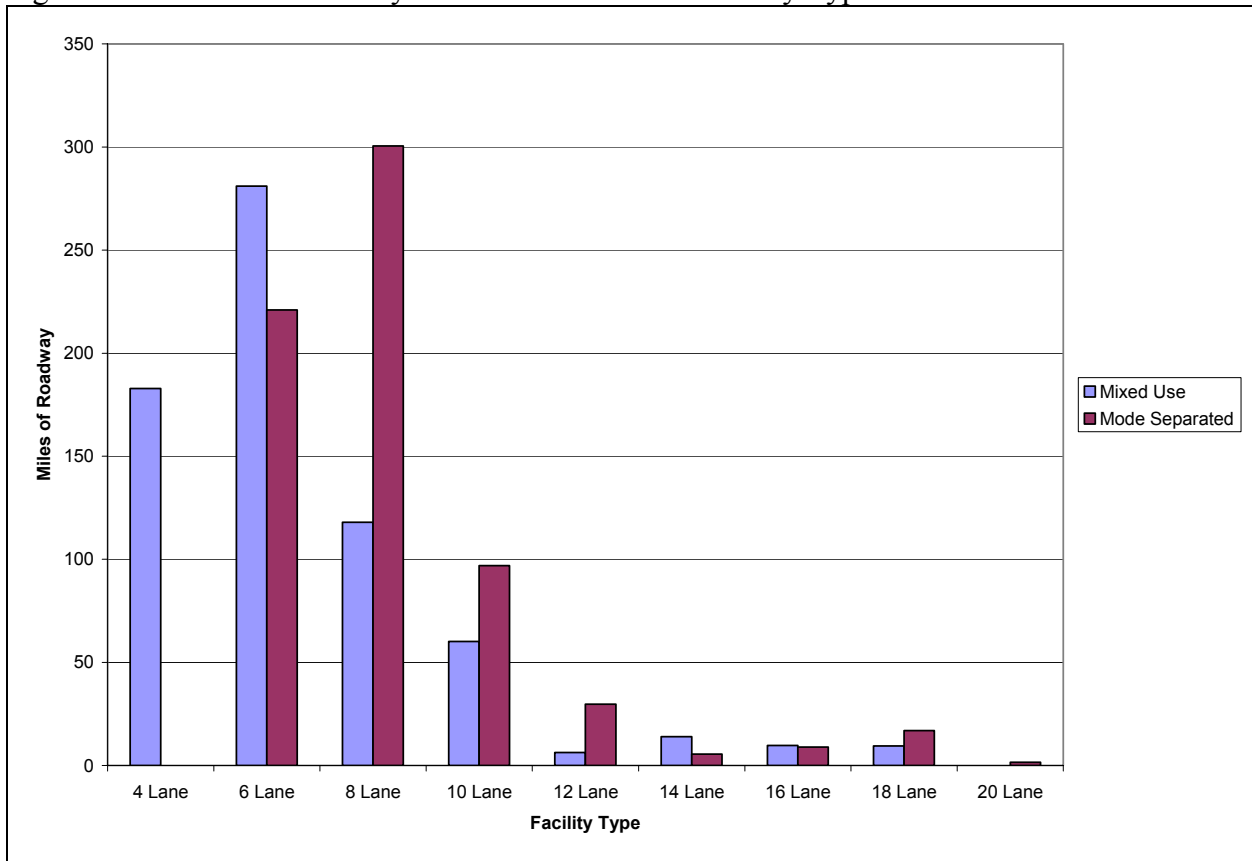
Figure 5 summarizes the total number of lanes that would be required to maintain LOS D for the mixed use facilities and mode separated facility. As can be seen from the figure, providing separate facilities for commercial and passenger car traffic would require more lanes per highway section to deliver the same LOS and operation. Peak hour LOS D can be maintained in 2030 with a total of 4,560 lane-miles of roadway when mixed use facilities are utilized. Providing separate facilities would require over 5,600 lane miles of roadway to maintain the same LOS for both facilities. Of the 681 miles of roadway in the study area, 255 miles of interstate would only require one lane in each direction to serve truck traffic while 357 miles would require two lanes in each direction and the remaining 69 miles would require three lanes in each direction.

The primary difference between the two alternatives is that mixed use facilities provide for a more efficient utilization of lane capacity than mode separated facilities would allow. For instance, on a given roadway segment, if passenger cars require a capacity of 5,000 passenger equivalents per hour (pcph) and trucks require 3,000 pcph capacity, this demand could be met with 4 lanes, assuming 2,000 pcph per lane, by providing a mixed use facility. However, a total of 5 lanes would be required to serve passenger car and truck traffic separately, since an extra full lane would be required to handle the extra demand for each facility.

While providing exclusive truck lanes is not shown to be as effective as widening for mixed use facilities on a statewide level, site specific implementation of this approach may be warranted for further examination. Specifically, providing exclusive truck lanes could eliminate speed differentials between passenger car traffic and truck traffic in hilly and mountainous areas with high percentages of truck traffic. In doing so, operational efficiency and crash experience could both be significantly improved.



Figure 25: Total Lane Miles by Number of Lanes and Facility Type



Figures 26 and 27 show the required number of lanes for each HPMS section to maintain peak hour LOS D for the mixed use and mode separate alternatives, respectively. Figure 28 shows the number of exclusive truck lanes that would be required for each HPMS Section.

Figure 26: 2030 Total Number of Lanes (Mixed Use Facility)

Figure 27: 2030 Total Number of Lanes (Mode Separated Facility)

Figure 28: 2030 Number of Exclusive Truck Lanes

## 6. SUMMARY OF OTHER INTERSTATE SAFETY AND CAPACITY STUDIES

One of the most comprehensive and progressive projects being proposed to address increasing truck traffic and capacity on interstates is the I-81 STAR Solutions Project in Virginia (3). A major component of this project is to separate passenger vehicles from trucks, and therefore, reduce the frequency of crashes and other incidents that result in injuries and major delays on the interstate. A public-private partnership approach is proposed to address the project development, construction, and management of this project. Other key project elements include the following:

- Upgrade all 325 miles of I-81 in Virginia
- Provide at least four lanes in each direction with at least two lanes for truck traffic
- Include directional dual interchanges with truck flyovers
- Build truck-only rest areas at six locations
- State-of-the-art tolling and intelligent transportation systems
- Improvement of 74 interchanges
- Rehabilitation of existing bridges
- Incorporate rail and intermodal options
- Provide 20-year pavement warranty
- Complete project within 15 years
- Use toll financing of bonds for and federal/state funding
- Total cost of approximately \$8 billion

A major interstate study that involves a multi-state coalition involves the I-10 corridor along the southern edge of the United States (4). Included are the states of California, Arizona, New Mexico, Texas, Louisiana, Mississippi, Alabama, and Florida. The purpose of the study was to analyze current and projected freight movements, assess how current and future freight volumes impact national and local transportation systems, and develop strategies for improving freight flow along the I-10 corridor. The study is intended to be a comprehensive evaluation to assess the feasibility of a broad range of options to facilitate the movement of goods along the corridor. Areas to be analyzed and evaluated within the corridor include air quality, highway safety, road maintenance, and the economies of adjacent areas. The following are findings from the study:

- Freight transportation is central to the performance of the U.S. economy, and a key contributor to U.S. competitiveness in the global marketplace.
- The continued trend toward a service economy, where reliability is essential, will increase the volume of freight traffic on highways at a projected pace nearly twice that of automotive traffic by 2025.

- Highways are essential to the efficiency of other freight transportation system elements, including ports, inland waterways and railroads.
- Increasing capacity in high-volume corridors is the single best method for lowering highway congestion.
- Increased funding is essential to guaranteeing that freight continues moving on highways as efficiently and productively as possible.
- Issues related to the demand for freight transportation transcend urban and state jurisdictions.
- The decision process for funding improvements should be based, in part, on a system of strategic gateways and corridors that facilitate the movement of freight and people, with recognition of jurisdictions that bridge high volume transportation corridors.

A more comprehensive and policy-oriented approach to the shortfall in highway capacity to handle project freight traffic was undertaken by the Reason Policy Institute in 2004 (5). Their recommended solution was to provide exclusive truck lanes to accommodate double and triple-trailer combination vehicles as a means of increasing capacity, improving safety, and realizing gains in the economy of shipping costs. The proposed solution was to construct toll truckways with heavy-duty, barrier-separated lanes added to existing interstates on which it would be legal to operate longer-combination vehicles. A survey of selected trucking companies indicated that they would be willing to pay tolls to obtain productivity gains from expanded operation of longer-combination vehicles, with the toll revenues offering significant potential as a funding source. The most promising interstate corridors were identified in terms of potential for revenue generation, available right-of-way, and the nature of the terrain through which they pass. After identifying nearly 50 possible corridors, projected 2020 truck volume was used to narrow the scope to 20 high-volume corridors between logical origins and destinations. Among other criteria, the following factors were scored for each potential corridor; 1) gross truck volume, 2) congestion, 3) connectivity, and 4) trucking company interest. The ten highest-scoring candidate corridors were identified and listed with a ratio of revenue potential/cost score. The two most attractive pilot corridors were I-80 from Chicago through Iowa and I-90 between Cleveland and the New York state line. It is interesting to note that I-75 was broken into two segments, with the Ohio to Michigan segment being ranked fourth nationally and the Florida to Ohio segment ranked fifth. The other north-south interstate corridor in Kentucky is I-65 and this route was ranked eighth nationally.

The Trans Texas Corridor is one state's vision of interstate travel in the future (6). It has been proposed to connect a 4,000-mile network of corridors up to 1,200 feet wide with separate lanes for passenger vehicles (three in each direction) and trucks (two in each direction). The corridor will also include six rail lines (three in each direction), one for high-speed passenger rail between cities, one for high-speed freight, and one for conventional commuter and freight. The third component of the corridor will be a 200-foot-wide dedicated utility zone. It is anticipated that the corridor will allow faster and safer transportation of people and freight, relieve congested roadways, separate the transport of hazardous materials from populated areas, improve air quality, and create new markets and jobs for the Texas economy. The project framework and funding has been approved through a state constitutional amendment that provides for public-

private partnerships and toll assessments on travelers. The corridors identified as highest priority include segments parallel to I-35, I-37, I-69 (proposed), I-45, and I-10. Estimated cost for the 4,000-mile corridor is \$31.4 million per centerline mile, or a total cost of \$125.5 billion, not including right-of-way and miscellaneous costs (\$145.2 to \$183.5 billion including these additional costs).

## 7. SUMMARY OF RESULTS AND CONCLUSIONS

Following is a summary of the primary conclusions resulting from analysis and evaluation of the safety, capacity, and delay issues related to interstates in Kentucky.

### *Future Traffic Projections*

- A clear upward trend in historical volumes has been observed on all interstate sections in Kentucky.
- Since the mid-1970's, annual growth in interstate traffic volumes has averaged 3.46 percent per year, which is a greater rate of increase than observed on non-interstate facilities and represents an approximate doubling of traffic every 20 years.
- Future growth in traffic on Kentucky interstates is projected to increase at a rate of 2.0 to 2.5 percent per year.

### *Recurring Congestion*

- Under 2003 conditions, 30 miles of interstate were found to operate at LOS F during the peak period, primarily on urban interstate sections.
- For 2030 projected traffic volumes, approximately 390 miles of interstate are expected to operate at LOS F, with 45 percent being rural interstate sections.
- Even though 80 percent of the total mileage and 60 percent of the total VMT on the study interstates occurred on rural interstates, less than one percent of the 2003 recurring delay occurred on rural interstates under 2030 conditions, rural interstates accounted for 36 percent of recurring congestion.
- Recurring traffic delay is expected to increase from 43 million vehicle-hours annually under 2003 demand to 860 million vehicle-hours in 2030.

### *Non-Recurring Congestion*

- Average incident duration for urban and rural interstates was calculated to be 0.76 hours and 1.12 hours, respectively.
- Rural interstates were shown to account for almost 20 percent of non-recurring delay, compared to less than 0.01 percent of recurring delay, under 2003 conditions. Under 2030 conditions, rural interstates were shown to account for almost 40 percent of non-recurring delay (36 percent of recurring congestion).
- Non-recurring delay was shown to provide significantly higher total delays compared to recurring congestion for both the existing and future conditions.
- Because highway incidents are unpredictable, the resulting non-recurring congestion can be more disruptive and costly than recurring peak hour congestion.

### *Crash Rates*

- The fatal crash rate on interstates in Kentucky is less than the national rate.
- Interstates have a much lower crash rate than other highway types.
- The total and injury crash rates for commercial vehicles on interstates is less than the corresponding overall rates.
- The fatal crash rate for commercial vehicles on interstate facilities is higher than the overall fatal rate.
- The overall crash rate is very similar on 4-lane and 6-lane interstates.
- The overall crash rate is less on 8-lane interstates as compared to 4-lane and 6-lane interstates.
- The crash rate for commercial vehicles is less on rural 6-lane interstates as compared to rural 4-lane interstates.
- For commercial vehicles on urban interstates, there is a pattern of increasing crash rates with increasing number of lanes.
- There were 48 interstate sections identified as having a critical overall crash rate.
- There were 26 interstate sections identified as having a critical commercial vehicle crash rate.

#### *Crash Rates and Operational Performance*

- As a general trend, overall crash rates increased with degradation of LOS and V/C.
- Commercial vehicle crash rates also increased with degradation of LOS and V/C.
- There was a general trend of increasing crash rates with an increase in interchange density.
- Of the variables considered to predict changes in crash rates due to changes in lane configurations, the most significant contributors to total crash rates on interstates were ADT and interchange density.

#### *Alternative Analysis*

- For the Build Alternative of expanding existing interstates from 4 to 6 lanes and 6 to 8 lanes, recurring and non-recurring congestion is expected to be reduced by 99 percent and 25 percent, respectively, under 2003 traffic demand and by 69 percent and 35 percent under 2030 traffic demand.
- For the Build Alternative of expanding exiting interstates from 4 to 6 lanes and 6 to 8 lanes, there were 110 of 161 sections evaluated with a B/C ratio greater than 1.0. 57 of these sections showed a B/C ratio greater than 2.5.
- Of the 10 sections with the highest B/C ratios, 8 are 4-lane facilities, seven of which are rural interstates.
- Widening interstates to provide exclusive truck lanes was not shown to be as effective as widening for mixed-use facilities on a statewide level.



## 8. REFERENCES

1. "HIGHWAY INFRASTRUCTURE", General Accounting Office, Report GA)-02-571, May 2002.
2. "Freight Shipments in America", 2002 Commodity Flow Survey, U.S. Department of Transportation, Bureau of Transportation Statistics, April 2004.
3. "Conceptual Proposal – Improvements to the I-81 Corridor", STAR Solutions, September 5, 2003.
4. Interstate 10 National Freight Corridor, i10freightstudy.org Website, April 2005.
5. "Corridors for Toll Truckways: Suggested Locations for Pilot Projects", Policy Study 316, Reason Public Policy Institute, February 2004.
6. "Crossroads to the Americas: Trans Texas Corridor Plan", Report Summary, Texas Department of Transportation, June 2002.
7. "Highway Statistics 2001", Report FHWA-PL-01-1011, U.S. Department of Transportation, Federal Highway Administration, November 2001.
8. "Highway Statistics 2002", U.S. Department of Transportation, Federal Highway Administration, November 2002.
9. "Highway Statistics, 2003", U.S. Department of Transportation, Federal Highway Administration, November 2003.
10. Green, E.R., et al. "Analysis of Traffic Crash Data in Kentucky (1999-2003, Report KTC-04-25/KSP2-02-1F, Kentucky Transportation Center, University of Kentucky, September 2004.
11. Deacon, I. A. et al., "Research Report UKTRP-87-32: Traffic Volume Estimates and Growth Trends." Kentucky Transportation Research Program, University of Kentucky, November 1987.
12. "Traffic Forecasting Report, 2004." Kentucky Transportation Cabinet, Division of Multi-Modal Programs, December, 2004.
13. "Highway Performance Monitoring System Field Manual, Appendix N Procedures for Estimating Highway Capacity. FHWA, Washington, D.C. 2003.
14. Chien, S.I. et al. "Simulation Based Estimates of Delays at Freeway Work Zones." Transportation Research Board 80th Annual Meeting, Washington, D.C., July 2000.
15. Blincoe, L, et al. "The Economic Impact of Motor Vehicle Crashes, 2000." NHTSA, Washington, D.C., May, 2002.

16. Weisbrod, G. Weisbrod, B. “Transportation Research Circular 477: Assessing the Economic Impact of Transportation Projects.” Transportation Research Board, October 1997.
17. FHWA Office of Operations Website. [http://ops.fhwa.dot.gov/program\\_areas/reduce-non-cong.htm](http://ops.fhwa.dot.gov/program_areas/reduce-non-cong.htm). May 3, 2005.

## **9. APPENDIX A: HPMS SECTION DATA**