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Effects of Differential Speed Limits on Vehicle Speed and Crash Characteristics Using Hypothesis Tests

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16. Abstract

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For the speed data, five measures of effectiveness (MOE's) were examined, including mean speed, speed variance, 85th percentile speed, median speed and noncompliance. For the crash data, crash rates were examined by collision type (e.g. rear-end), vehicle type involved (any vehicle or truck involved) and crash severity.

In crash analysis, this study did not find any obvious relationship between the crash rates and speed limits, and thus no evidence was found to support that either DSL or uniform speed limits are more beneficial to vehicle safety on rural Interstate highways.

In speed analysis, the mean speed of all vehicles on the rural Interstate highways kept a natural increasing trend regardless of speed limit changes.

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A Research Project Report
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Abbreviations

State Abbreviations:

AZ – Arizona

AR – Arkansas

CA – California

ID – Idaho

IL – Illinois

IN – Indiana

IA – Iowa

MO – Montana

NC – North Carolina

VA – Virginia

WA - Washington

Others:

DSL – Differential Speed Limits for passenger cars and trucks on rural Interstate highways

UNI – Uniform Speed Limits for passenger cars and trucks on rural Interstate highways

ADT – Average Daily Traffic

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Chapter 1 Introduction

In 1987, the enactment of Surface Transportation Uniform Relocation Assistance (STURA) Act abolished the "National Maximum Speed Limit", which was a uniform 88.50 km/h (55 mi/h) for all types of vehicles on rural Interstate highways in consideration of gas crisis in the 1970's. In the year following STURA, 39 states increased their speed limits, followed by 8 additional states in the years since (according to National Safety Council, 1997).

However, based on different acknowledgement of possible safety impacts, for which increased speed limit would account, the states altered their speed limits in different ways. Some increased the speed limits for both passenger cars and large trucks by the same amounts, for example, Iowa changed its speed limits for both of these two types of vehicles from 88.50 km/h (55 mi/h) to 104.59 km/h (65 mi/h) in 1988; some states increased the two limits by different amounts, which resulted in Differential Speed Limits (DSL) for passenger cars and large trucks. Illinois for example, kept the speed limit for large trucks unchanged at 88.50 km/h (55 mi/h), and raised that for cars to 104.59 km/h (65 mi/h).

In recent years, a lot of research has been conducted to investigate the impacts between DSL and uniform speed limits on car crashes and speed distributions. However, these studies suffered from two weaknesses. First, they were conducted shortly after differential speed limits were enacted, meaning that long-term effects of DSL were not examined. Second, the findings of these studies were not consistent: some concluded that DSL had no effect on safety and others concluded that DSL had significantly improved safety (in some cases) or had an adverse effect (in some other cases). This study is revisiting this topic, with the available new data from as many states as possible, which include the states of Arizona, Arkansas, Idaho, Illinois, Indiana, Iowa, Missouri, North Carolina and Virginia.

In this study, two key questions were explored:

- What kind of impact and to what extent do different types of speed limits have on traffic safety, i.e., the type and number of crashes, types of vehicles involved in the crashes, and severity of crashes?

- What kind of impact and to what extent do different types of speed limits have on the actual speed distribution characteristics of vehicles on the rural Interstate highways?

To answer these two questions, this study used these new data from both DSL areas and areas with uniform speed limits to statistically analyze and compare the impacts of DSL and non-DSL (uniform speed limits) on safety and speed distribution characteristics.

Chapter 2 Literature Review

Since the enactment of DSL on the Interstate highway systems, there have been concerns about its impacts on traffic safety, travel speed and other transportation conditions. As a result, a number of research projects have been conducted to investigate these issues.

Studies on the impact of DSL on Crashes

The most controversial topic on the impacts of DSL is its influence on traffic safety. Since the motivation for employing DSL was to make the truck drivers have sufficient time and distance to react when an emergency occurs on the road, which potentially reduces crashes as a result, the DSL's actual impact on traffic crashes has always drawn the most attention from researchers.

A study by Harkey and Mera[2] in 1994 examined the safety impact of DSL, based on investigation of speed data from 11 states, with a total of 26 sites. Four types of speed limits were employed in those 26 sites (which were grouped into pairs), with one site under a uniform speed limit of either 104.59 km/h (65 mi/h) or 88.50 km/h (55 mi/h), the other under a DSL of either 104.59/88.50 km/h (65/55 mi/h) or 104.59/96.54 km/h (65/60 mi/h). The study investigated the percentage of different collision types for the total number of crashes for each of four types of speed limits. Three types of collisions were taken into consideration: rear-end crashes, sideswipe crashes, and all other crashes. This analysis also took into consideration vehicle types (passenger cars and trucks). The results are presented in Table 1:

Table 1 Accident proportions by speed limit and vehicle type/collision type categories (Transformed from Table 32, Reference 1)

Car/Truck Speed Limit (km/h (mi/h))	Rear-End		Sideswipe		Other	
	Car-into-Truck	Truck-into-Car	Car-into-Truck	Truck-into-Car	Car-into-Truck	Truck-into-Car
88.50/88.50 (55/55)	18.35	12.35	28.52	27.77	3.34	1.75
104.59/88.50 (65/55)	11.51	8.42	21.23	16.25	1.75	1.01
104.59/96.54 (65/60)	16.98	4.51	21.95	13.03	2.54	0.96
104.59/104.59 (65/65)	8.43	10.25	19.99	18.84	2.31	2.09
Uniform (104.59/104.59 (65/65) and 88.50/88.50 (55/55))	10.91	10.78	22.12	21.07	2.57	2.01
Differential (104.59/88.50 (65/55) and 104.59/96.54 (65/60))	13.70	6.86	21.52	14.96	2.07	0.99

Note: The numbers shown in fields CT and TC stand for the proportions of the certain type of accident to the all accident accounts.

As shown in Table 1, the higher proportion of accidents happened in states employing Uniform speed limits in both Sideswipe and any other accidents regardless of the vehicle type. For Rear-End accidents, a higher proportion of Truck-into-Car collisions occurred in the Uniform group, while more Car-into-Truck collisions happened in the DSL group.

In Garber and Gadiraju's study[3] in the beginning of the 1990's, analysis was conducted based on extensive data from 11 sites. These sites were located in 3 states with DSL, which were California, Michigan and Virginia, and two states without DSL, which were Maryland and West Virginia. The data covered the time durations before and after the implementation of speed limit changes for the DSL states. The analysis compared crash rates of Before and After periods by severity and collision type. The results showed no statistically significant differences in any of the comparisons. Based on these results, the authors concluded that DSL was not more effective than uniform speed limits in reducing traffic crash risk.

Studies on the impact of DSL on Mean Speed

In 1990, Freedman and Williams[4] analyzed speed data, which were collected at 54 sites in 11 Northeastern states, to determine the effect of DSL on mean and 85th percentile speeds. Those states included six which remained the uniform 88.50 km/h (55 mi/h) speed limit, three which raised speed limits both for cars and trucks to 104.59 km/h (65 mi/h), and two employing DSL of 104.59/88.50 km/h (65/55 mi/h). The results showed that for passenger cars, the mean speed and 85th percentile speed (108.9 and 116.2 km/h (67.7 and 72.2 mi/h)) in states with DSL were not significantly different from the states with a uniform 104.59 km/h (65 mi/h) for all vehicles (107.3 and 116.0 km/h (66.7 and 72.1 mi/h)). The mean and 85th percentile speeds of trucks (98.8 and 106.7 km/h (61.4 and 66.3 mi/h)) in the states with DSL were very close to the respective speeds of trucks (97.0 and 105.1 km/h (60.3 and 65.3 mi/h)) in the states with uniform speed limits. The analysis also obtained similar results when comparing the percentage of vehicle compliance.

Harkey and Mera[2] also studied the impact of DSL on vehicle speeds. The results showed no significant difference for passenger car mean speeds (108.8, 108.4 and 109.1 km/h (67.6, 67.4 and 67.8 mi/h) respectively), and a slight difference on truck mean speeds between those three speed limits (102.7, 98.3 and 102.3 km/h (63.8, 61.1 and 63.6 mi/h)).

Garber and Gadiraju[3] also conducted a before-and-after analysis on speed characteristics. The results indicated an increase on passenger cars' mean speed with raising the speed limit for those vehicles, and also a significant difference between truck mean speeds under DSL and non-DSL.

Studies on the impact of DSL on Speed Variance

In Garber and Gadiraju's study[3], speed variance was examined based on data obtained from Virginia, a state with a DSL of 104.59/88.50 km/h (65/55 mi/h), and West Virginia, where no DSL was enacted. According to the results, speed variances for all types of vehicles were significantly greater in the DSL sites than in non-DSL sites, which meant implementation of DSL tended to increase the interactions between vehicles, and thus potentially increase the possibility of some types of crashes.

Harkey and Mera's result[2] also indicated that 10 of 13 site pairs showed significant differences between the speed variances of all vehicles. The same conclusion was drawn for truck speed variances. However, no significant differences were found on car speed variances in the 13 site pairs. Furthermore, they found no difference between the speed distributions for both cars and trucks for the 104.59/96.54 km/h (65/60 mi/h) and 104.59/104.59 km/h (65/65 mi/h) speed limits.

From the literature review, one can see that the results of previous research show diverse conclusions. In this study, new data and longer analysis duration, 1991 to 2000, were employed to revisit this topic.

Chapter 3 Methodology

In this study, a six-step analysis methodology was employed. Figure 1 illustrates the flowchart of the methodology. The six steps shown in the flowchart are explained from Section 3.1 to Section 3.5.

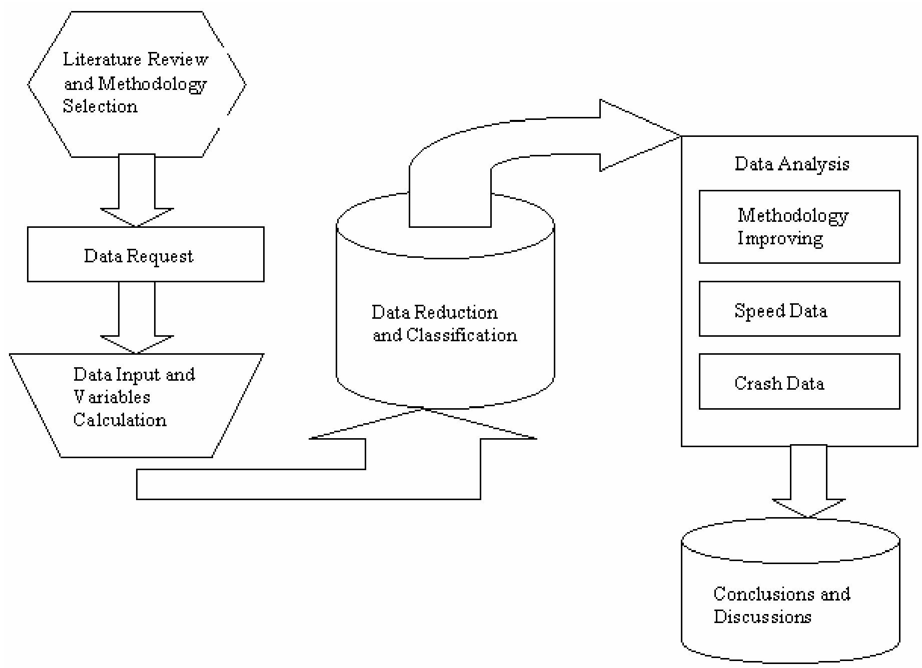

Figure 1 Methodology Flowchart

3.1 Literature Review and Methodology Pre-Selection

In this first step of this study, some previous relevant research was reviewed, and their methodologies and results were examined. Based on the evaluation results of the analysis methodologies, the most suitable one was selected for this study. Finally, statistical methodology was selected to conduct analyses on both crash data and speed data. The statistical methods include one-way ANOVA and two multi-comparison tests, namely Tukey test and Dunnett test. These tests are introduced in Section 3.5.1.
The study duration was limited to the 1990's. And the analysis variables are listed below:

Crash Analysis:

- Total Crash Rate
- Fatal Crash Rate
- Rear-End Crash Rate

- Total Truck-involved Crash Rate
- Truck-involved Fatal Crash Rate
- Truck-involved Rear-End Crash Rate

Speed Analysis:

- Mean Speed
- Speed Variance
- Median Speed
- 85th percentile Speed
- Noncompliance (the percentage of vehicles exceeding speed limits)

Similar to the previous studies described in literature survey, based on the actual implementation situations of DSL in different states, some states are selected to represent the four types of possible DSL implementation combinations:

- Always kept DSL in the 1990's
- Always kept Uniform in the 1990's
- Transferred from DSL to Uniform in the 1990's
- Transferred from Uniform to DSL in the 1990's

3.2 Data Request

After making the decisions on variables of interest, requests for data were sent out in June of the year 2001 to the traffic data management agencies in each state, either via electronic mail or telephone. The states chosen are listed as follows: Arizona, Arkansas, California, Delaware, Idaho, Illinois, Indiana, Iowa, Missouri, North Carolina, Ohio, Oregon, Texas, Virginia, Washington and West Virginia. As expected, data were obtained from a major portion of the states. Table 2 and Table 3 summarize the speed and crash data obtained, and their format.

Table 2 Summary of Speed data obtained

State	Carrier	Variables that could be calculated					Years of Data
		Mean Speed	Speed Variance	Median Speed	85% Speed	Noncompliance	
CA	Electronic	x		x			1999, 2000
ID	Electronic	x			x		1991 -1999
IL	Electronic	x	x	x	x	x	1993 - 1994, 1997 - 1999
IN	Electronic	x		x	x		1991, 2000
IA	Hardcopy	x					1994-2000
NC	Hardcopy	x	x		x		1991 - 1994
TX	Electronic	x	x		x		1998 - 2000
VA	Electronic, Hardcopy	x	x	x	x	x	1991 - 2000
WA	Electronic	x	x	x	x	x	1998 - 2001

Table 3 Summary of Additional Crash data obtained

State	Carrier	Years of Data	Additional Variables Obtained	# of Sites
AZ	Electronic	1991 - 2000	Average Daily Traffic	278
AR	Electronic	1991 - 1995 1997 - 1999	Average Daily Traffic	10
CA	Electronic	1991 - 2000	Truck-involved Fatal Crashes, Truck-involved Rear-end Crashes	10
ID	Electronic	1991 - 2000	Truck-involved Fatal Crashes, Truck-involved Rear-end Crashes, Average Daily Traffic	29
IL	Hardcopy	1993 - 1999	Truck-involved Rear-end Crashes, Average Daily Traffic	5
IN	Electronic	1995 - 1999	N/A	2
IA	Hardcopy	1993 - 1999	Truck-involved Fatal Crashes, Truck-involved Rear-end Crashes	7
MO	Electronic	1991 - 1999	Average Daily Traffic	3
NC	Electronic	1997 - 2000	Truck-involved Fatal Crashes, Average Daily Traffic	26
VA	Hardcopy	1991 - 1993 1995 - 1999	Truck-involved Fatal Crashes, Average Daily Traffic	267
WA	Electronic	1991 - 2000	Truck-involved Fatal Crashes, Average Daily Traffic	6

Note: For all states, total crashes, fatal crashes, rear-end crashes and total truck-involved crashes were obtained. Table 3 shows only the availabilities of other additional variables obtained from the states.

3.3 Data Input, Reduction and Compilation

First, the data received in hardcopy were recorded into the computer manually. The speed data from Iowa, for example, were obtained as a seasonal statistics report. The vehicle speeds were tabulated in bins with ranges of 16.1 km/h (10 mi/h) for each season from 1994 to 2000. Those speeds were scanned into the computer, and calibrated with a visual check. This procedure was the basis for the following data reduction and compilation.

Then, variables were compiled from the raw data, and during the compilation, some impropriate portions of data were removed from the data set. Take the 24-hour traffic data of example. Since this type of data only records the information about individual vehicles, namely axles of the vehicle, distances of every two next axles of this vehicle, its speed and the time it passed the counter loop, it is necessary to calculate each variable which is needed in the following analysis. Here is a brief explanation of the procedure of processing this kind of 24-hour data:

1. Conversion of the original data file from unformatted text file into formatted data forms
2. Removal of the obvious errors. In every 24-hour count file, there showed less than 20 "vehicles" with a speed of less than 8.0 km/h (5 mi/h), and a total axle-distance less than 4 feet. These were removed as abnormal records from the data.
3. Calculation of the necessary speed variables

For speed data, ADT was used as a major factor to filter the data points. The purpose was to reduce the potential impacts on speed distribution, which are possibly caused by variation of ADT.

For crash data, ADT was also used to filter the data. However, for the purpose of comparison, analyses were also conducted for all data in Crash Analysis.

The speed and crash data summaries for each state after the two steps above are shown here in Table 4, Table 5 and Table 6:

Table 4 Summary of Speed data after data reduction and classification

Group	State	Speed Data Availability					# of Sites	Years of Data
		Mean Speed	Speed Variance	85% Speed	Median Speed	Noncompliance		
1	IA	x	N/A	N/A	N/A	N/A	1 -- 27	1991 - 2000
2	IL	x	x	x	x	x	4	1993, 1994, 1997 - 1999
	IN	x	N/A	x	x	N/A	4, 3	1991, 2000
3	ID	x	N/A	x	N/A	N/A	24 -- 38	1991 - 1999
4	VA	x	x	x	x	x	3 -- 7	1991, 1993, 1995, 2000, 2001

Note: For speed data, the numbers of sites vary in years for some states, this is why in the column "# of Site" some ranges are shown for some states.

Table 5 Summary of Crash data after data reduction (after ADT filtering)

Group	State	Crash Data Availability						# of Sites	Years of Data
		All Vehicles			Truck-involved				
		Total Crash Rate	Fatal Crash Rate	Rear-end Crash Rate	Total Crash Rate	Fatal Crash Rate	Rear-end Crash Rate		
1	NC	x	x	x	x	x	x	26	1991-1995 1997-2000
	AZ	x	x	x	x	x	x	278	1991-2000
	MO	x	x	x	x	N/A	N/A	3	1991-1999
2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3	ID	x	x	x	x	x	x	29	1991-2000
	AR	x	x	x	x	N/A	N/A	10	1991-1995 1997-1999
4	VA	x	x	x	x	x	N/A	267	1991-1993 1995-1999

Table 6 Summary of Crash data after data reduction (after ADT filtering)

Group	State	ADT Range	Crash Data Availability						# of Sites	Years of Data
			All Vehicles			Truck-involved				
			Total Crash Rate	Fatal Crash Rate	Rear-end Crash Rate	Total Crash Rate	Fatal Crash Rate	Rear-end Crash Rate		
1	NC	10000-30000	x	x	x	x	x	x	8	1991-1995 1997-2000
	AZ	10000-25000	x	x	x	x	x	x	30	1991-2000
	MO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3	ID	4000-10000	x	x	x	x	x	x	13	1991-2000
	AR	20000-35000	x	x	x	x	N/A	N/A	5	1991-1995 1997-1999
4	VA	12000-20000	x	x	x	x	x	N/A	66	1991-1993 1995-1999

Note: In the data summary tables 4, 5 and 6, “x” indicate that the correspondent data are available.

3.4 Data Analysis

In this study, the major methods used were statistical comparison tests. Figure 2 shows the flowchart of the entire analysis process. Crash analysis on total crash rates in North Carolina is given as an example in Section 4.3.1 in Chapter 4 Crash Data Analysis.

3.4.1 Post-Hoc Tests Introduction

In this study, several Post-Hoc (or Multi-Comparison) tests were used to identify the differences among data groups. These tests are introduced briefly in the following sections.

3.4.1.1 Why Post-Hoc

A one-way ANOVA test can tell if there are any differences among the data groups, by calculating the F-ratio and P-Value. However, in the case that significant differences are found among more than two groups, the ANOVA itself cannot indicate where the differences lie. In this circumstance, Post-Hoc tests are effective tools to locate the differences by conducting pairwise comparisons for each pair of groups.

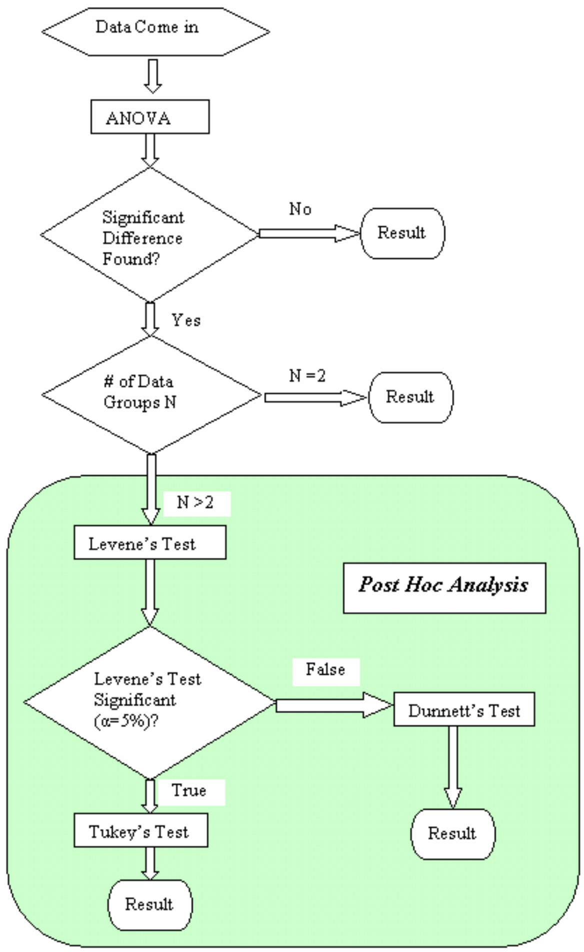

Figure 2 Data Analysis Process Flowchart

3.4.1.2 Levene's Test for Homogeneity of Variance[5, 6, 7]

Levene's test is used to test if k samples have equal variances. Equal variances across samples are called homogeneity of variance. The Levene test is defined as:

H_0 : $F_1 = F_2 = \ldots = F_k$;

Ha : $F_i \neq F_j$, for at least one pair (i, j).

Test Static:

$$W = \frac{(N-k)\sum_{i=1}^{k} N_i(\overline{Z}_{i.} - \overline{Z}_{..})^2}{(k-1)\sum_{i=1}^{k}\sum_{J=1}^{Ni}(Z_{ij} - \overline{Z}_{i}.)^2}$$

Where:

N – Total sample size
Ni – Sample size of the *i*th subgroup

k – Number of subgroups
$\overline{Z}_{i.}$ – The group means of the Zij
$\overline{Z}_{..}$ – The overall mean of the Zij
Zij = $\left| Y_{ij} - \hat{Y}_{i.} \right|$
Y_{ij} – data point
$\hat{Y}_{i.}$ – The mean of the *i*th sub group

The Levene test rejects the hypothesis that the variances are equal if

$$W > F_{(\alpha, k-1, N-k)}$$

Where $F_{(\alpha, k-1, N-k)}$ is the upper critical value of the F distribution with k-1 and N-k degrees of freedom at a significance level of α.

3.4.1.3 Tukey Test[5, 6, 7]

The Tukey test, which is sometimes called the HSD (honestly significant difference) test, is aimed to examine all pairwise comparisons $\{u_i - u_j\}$ with the significance level α. This test calculates a confidence interval for each pair of means. The interval is:

$$(\overline{Xi} - \overline{Xj}) \pm q_{\alpha;k,N-k} \sqrt{MS_w / n} \qquad \text{(i, j = 1, …, r; i} \neq \text{j)}$$

Where X_i and X_j represent the means for any two groups, q is a tabled value, MS_w is the means square for error in ANOVA, and n is the assumed common group size.

The hypotheses of Tukey Test are:

H_0: Xi = Xj (i, j = 1, …, r; i ≠ j)

H1: Xi ≠ Xj (for at least one pair of i and j; i, j = 1, …, r; i ≠ j)

Although when developing this method, Tukey assumed that the group sizes should be equal, but in practice, various studies (Dunnett, 1980; Kesselman, Murray & Rogan, 1976) show that the Tukey method also applies in unequal situations, provided that the n is replaced by the harmonized group size $2n_1n_2/(n_1+n_2)$. However, the Tukey test only applies when the groups have homogeneous variances, meaning that the variances of groups are equal.

3.4.1.4 Dunnett's Test[5, 6, 7]

Dunnett's test is used when the variances of comparison groups are not equal. Two means are significantly different if

$$\left|\overline{x_i} - \overline{x_j}\right| \geq Q^*{}_{i,j} R_{\varepsilon,\gamma,v}$$

Where

$$Q^*{}_{i,j} = \sqrt{\frac{s_i^2}{n_i} + \frac{s_j^2}{n_j}}$$

$$R_{\varepsilon,\gamma,v} = \frac{(S_{\varepsilon,k,n_i-1} s_i^2 / n_i + S_{\varepsilon,k,n_j-1} s_j^2 / n_j) / \sqrt{2}}{s_i^2 / n_i + s_j^2 / n_j}$$

$S_{\varepsilon,r,m}$ is the upper-ε critical point of the distribution of the Studentized Range

$$S_{r,m} = \frac{\max(x_1,\ldots x_\gamma) - \min(x_1,\ldots x_\gamma)}{s_m}$$

The hypotheses of Dunnett Test are:

H_0 : $X_1 = X_2 = \ldots = X_r$;

Ha : $Xi \neq Xj$, for at least one pair (i, j).

3.4.2 Analysis on Crash Data

The safety issue is the most controversial where the impacts of DSL on rural Interstate highways are being considered. To assess these impacts, crash rates were compared for the following variables in this analysis:

- Total Crash Rate
- Fatal Crash Rate
- Rear-End Crash Rate
- Total Truck-involved Crash Rate
- Truck-involved Fatal Crash Rate
- Truck-involved Rear-End Crash Rate

The crash rates are calculated by the following formula[8]:

$$CR = \frac{CC * 100{,}000{,}000}{L * ADT * 365}$$

Where:

CR – Crash Rate
CC – Crash Count
L – Length of the highway section
ADT – Average Daily Traffic of the highway section

Comparisons on crash rates were conducted in two different ways, and the procedure flowchart is illustrated in Figure 2.

1. Yearly comparison. In a specific state, simple one-way ANOVA tests were conducted on yearly crash data for each variable to determine whether any significant difference (α = 5%) existed among the yearly groups. If there were no difference, no more analysis would be needed. If significant differences were found, a multi-comparison test (Tukey test or Dunnett test) was used to examine where the difference exists. For the description of the Multi-comparison tests, please refer to section 3.5.1.
2. "Before" and "After" comparison. In this comparison, the crash rates in a certain state were grouped into two categories: Before and After the implementation of the speed limits change. These two groups of data were compared by ANOVA, to examine if there was a significant difference between them.

3.4.3 Analysis on Speed Data

In order to assess the impacts of speed limits on vehicle speed distribution characteristics, five major variables were employed in this research:

- Mean Speed for all Vehicles
- Speed Variance for All Vehicles
- 85th Speed for All Vehicles
- Median Speed for All Vehicles
- Noncompliance for All Vehicles, i.e. the percentage of vehicle exceeding the speed limits

These five variables were compared in each individual state, based on the data availability. The same process as used in the Crash Data Analysis was used in the Speed Data Analysis.

Chapter 4 Crash Data Analysis

In this study, six states were divided into four groups as shown in Section 4.1. In each state, based on data availability, six or fewer variables were taken into consideration: Total Crash Rate, Fatal Crash Rate, Rear-end Crash Rate, Total Truck-involved Crash Rate, Truck-involved Fatal Crash Rate and Truck-involved Rear-end Crash Rate. For each variable in every state, two types of analyses were done: Before-After comparison and Year-Pair analysis (pairwise comparison on each pair of years by one-way ANOVA and Post-Hoc Comparison). In the Before-After comparison, data were divided into two groups, the Before period and the After period, which were based on the dates on which changes on speed limits were implemented in a certain state. For those states that never changed their policy, the data were categorized into two virtual groups, 1990 - 1995 and 1996 - 2000, to act as controls. These analyses were conducted on all crash data first, and then the same analysis procedures were applied to crash data after ADT filtering, in order to reduce the potential impacts of the variation of ADT on crash rates. Shown in Appendix 3 is the method used to filter crash data by ADT, which was employed in speed data analysis as well.

4.1 Groups Information

Table 7 shows the grouping of all states, which were employed in this study. Among the nine states, six had crash rate data available, namely Arizona, Missouri, North Carolina, Arkansas, Idaho and Virginia.

Table 7 Summary of Four Groups

	Grouping	Data Availability	
Group 1: (UNI-UNI)	**Speed Limit Changes**	Crash Rate	Speed
AZ	Always 120.68/120.68 km/h (75/75 mi/h)	Y	N
IA	Always 104.59/104.59 km/h (65/65 mi/h)	N	Y
MO	88.50/88.50 km/h (55/55 mi/h) → 112.63/112.63 km/h (70/70 mi/h), 1996	Y	N
NC	104.59/104.59 km/h (65/65 mi/h) → 112.63/112.63 km/h (70/70 mi/h), 1996	Y	N
Group 2: (DSL-DSL)	**Speed Limit Changes**		
IL	Always 112.63/104.59 km/h (70/65 mi/h)	N	Y
IN	Always 104.59/96.54 km/h (65/60 mi/h)	N	Y
Group 3: (UNI-DSL)	**Speed Limit Changes**		
AR	104.59/104.59 km/h (65/65 mi/h) → 112.63/104.59 km/h (70/65 mi/h), Aug 1996	Y	N
ID	104.59/104.59 km/h (65/65 mi/h) → 120.68/120.68 km/h (75/75 mi/h) → 120.68/104.59 km/h (75/65 mi/h), May 1996 and July 1998	Y	Y
Group 4: (DSL-UNI)	**Speed Limit Changes**		
VA	104.59/88.50 km/h (65/55 mi/h) → 104.59/104.59 km/h (65/65 mi/h), July 1994	Y	Y

Each group involved in crash analysis is given brief introduction below.

Group 1 (UNI-UNI) included three states, which always kept uniform speed limits for passenger cars and trucks throughout the 1990's. Among them, Arizona and North Carolina never changed their speed limits, and Missouri raised its from 88.50/88.50 km/h (55/55 mi/h) to 112.63/112.63 km/h (70/70 mi/h). This group was used as a control group, to examine the natural developing trends of crash rates with uniform speed limits.

Group 2 (DSL-DSL) would include those states which kept DSL throughout 1990's. However, due to the lack of data, no research was done for this group.

Group 3 (UNI-DSL) includes two states, which switched from uniform speed limits to DSL during the 1990's. Arkansas raised the speed limit for passenger cars from 104.59 km/h (65 mi/h) to 112.63 km/h (70 mi/h), while it kept trucks at 104.59 km/h (65 mi/h) unchanged, in August 1996. In Idaho, the situation was more complicated. This state changed its speed limits twice. In May 1996, speed limits for passenger cars and trucks were raised by the same amount from 104.59 km/h (65 mi/h) to 120.68 km/h (75 mi/h), which resulted in a uniform 120.68/120.68 km/h (75/75 mi/h). Twenty-six months later, in July 1998, trucks' speed limit was decreased to 104.59 km/h (65 mi/h), which resulted in a DSL condition finally.

Group 4 (DSL-UNI) only contains Virginia, which raised speed limits from 104.59/88.50 km/h (65/55 mi/h) to 104.59/104.59 km/h (65/65 mi/h) in July 1994.

4.2 Data Summary

This section gives the summary of the crash data. Analyses were conducted both on the complete set of data (Table 8) and on the portion of data that has been filtered based on ADT (Table 9). This ADT filtering removes sites that have relatively high or low ADT's, as described in the Appendix 3.

Table 8 Summary of All Crash Data

Group	State	Speed Data Availability					# of Sites	Years of Data
		Mean Speed	Speed Variance	85% Speed	Median Speed	Noncompliance		
1	IA	x	N/A	N/A	N/A	N/A	1 -- 27	1991 - 2000
2	IL	x	x	x	x	x	4	1993, 1994, 1997 - 1999
	IN	x	N/A	x	x	N/A	4, 3	1991, 2000
3	ID	x	N/A	x	N/A	N/A	24 -- 38	1991 - 1999
4	VA	x	x	x	x	x	3 -- 7	1991, 1993, 1995, 2000, 2001

Table 9 Summary of Crash Data after ADT Filtering

Group	State	Crash Data Availability						# of Sites	Years of Data
		All Vehicles			Truck-involved				
		Total Crash Rate	Fatal Crash Rate	Rear-end Crash Rate	Total Crash Rate	Fatal Crash Rate	Rear-end Crash Rate		
1	NC	x	x	x	x	x	x	26	1991-1995 1997-2000
	AZ	x	x	x	x	x	x	278	1991-2000
	MO	x	x	x	x	N/A	N/A	3	1991-1999
2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3	ID	x	x	x	x	x	x	29	1991-2000
	AR	x	x	x	x	N/A	N/A	10	1991-1995 1997-1999
4	VA	x	x	x	x	x	N/A	267	1991-1993 1995-1999

Note: In Table 8 and Table 9, “x”s indicate that the correspondent data are available.

4.3 Crash Analysis Results

In this section, the crash analysis results are presented by variable. To clarify the analysis methodology, in Section 4.3.1, North Carolina is used as an example, to illustrate the process. After presentations of analysis results on each variable, conclusions are drawn, followed by discussions.

4.3.1 Crash Analysis Example: Total Crash Rate in North Carolina

This section uses the variable Total Crash Rate of North Carolina as an example to clarify the crash analysis process,

Table 10 shows a sample of the North Carolina data ready to be analyzed:

First, the variable Total Crash Rate (totalr) was used to perform an ANOVA between the Before and After periods, using the grouping factor *bora* (H_0: $TCR_{Before} = TCR_{After}$).

The descriptive statistics of the data were calculated, to provide a general background as shown in Table 11. The ANOVA results are shown in Table 12.

Table 10 Sample crash data of North Carolina

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1 : year 1991

	year	bora	length	adt	totalr	fatalr	rearendr	truckttr	truckftr	truckrer	var	var
1	1991	1.00	4.02	9800	27.8	.00	.00	.00	.00	.00		
2	1991	1.00	4.20	9900	26.4	.00	.00	6.59	.00	.00		
3	1991	1.00	4.24	10400	49.7	.00	6.21	.00	.00	.00		
4	1991	1.00	4.30	22100	14.4	.00	5.77	2.88	.00	5.77		
5	1991	1.00	4.38	8900	42.2	.00	.00	7.03	.00	.00		
6	1991	1.00	4.41	14800	29.4	.00	8.40	16.79	.00	8.40		
7	1991	1.00	4.45	22700	46.1	.00	8.14	5.42	.00	2.71		
8	1991	1.00	4.60	17100	10.4	.00	.00	6.97	.00	.00		
9	1991	1.00	4.83	23300	36.5	.00	2.43	9.74	.00	.00		
10	1991	1.00	4.96	14200	27.2	.00	3.89	.00	.00	.00		
11	1991	1.00	5.19	10800	19.6	.00	9.78	.00	.00	.00		
12	1991	1.00	5.23	13000	20.1	.00	.00	8.06	.00	.00		
13	1991	1.00	5.49	24200	37.1	.00	2.06	10.31	.00	2.06		
14	1991	1.00	5.85	10800	26.0	.00	.00	4.34	.00	.00		
15	1991	1.00	5.92	17100	16.2	.00	2.71	8.12	.00	2.71		
16	1991	1.00	6.22	29500	35.8	1.49	8.96	4.48	.00	2.99		
17	1991	1.00	6.25	17000	18.0	.00	.00	2.58	.00	.00		
18	1991	1.00	6.29	22200	25.5	.00	5.89	3.92	.00	1.96		
19	1991	1.00	6.60	29900	36.1	4.16	4.16	9.72	1.39	1.39		
20	1991	1.00	6.80	9800	37.0	.00	.00	8.22	.00	8.22		

Data View / Variable View

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Note: Definitions of variables in this table are given explanations as follows:

- bora – Grouping factor, where 1.00 stands for the Before period, and 2.00 for the After period
- length – Length of the rural Interstate highway section where crash data were collected
- ADT – Average Daily Traffic on the rural Interstate highway section
- totalr – Total crash rate
- totalr – Total crash rate
- fatalr - Fatal crash rate
- rearendr – Rear-end crash rate
- truckttr – Total truck-involved rear-end crash rate
- truckftr – Truck-involved fatal crash rate
- truckrer – Truck-involved rear-end crash rate

Table 11 Descriptive Statistics of Total Crash Rates in North Carolina for the Before and After Periods

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
TOTALR	1.00	130	37.06	14.22	1.25	34.60	39.53	10.45	79.61
	2.00	104	42.71	17.31	1.70	39.34	46.08	6.20	127.57

Note: 1.00 and 2.00 are grouping factors, meaning Before and After periods respectively.

Table 12 ANOVA Results of Total Crash Rates in North Carolina for the Before and After Periods

		Sum of Squares	df	Mean Square	F	Sig.
TOTALR	Between Groups	1842.51	1	1842.51	7.504	0.007
	Within Groups	56961.53	232	245.52		

Then, the variable Total Crash Rate was grouped by year. An ANOVA was performed first, to check if any difference existed among the yearly crash rates (H_0: $TCR_{1991} = TCR_{1992} = \ldots = \text{Total Crash Rate}_{2000}$). When any differences were found, a Levene's Test was conducted, and based on the Levene's Significance given by Levene's Test, a certain Post-Hoc (or Multi-Comparison test) was used to locate the difference.

Table 13 Descriptive Statistics of Total Crash Rates in North Carolina by year

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1991	26	29.98	10.31	2.02	25.82014266	34.15	10.45	49.7
1992	26	34.16	10.26	2.01	30.02	38.3	15.19	51.93
1993	26	41.74	15.41	3.02	35.51	47.96	17.3	73.12
1994	26	37.98	17.14	3.36	31.06	44.9	10.83	79.61
1995	26	41.46	14.01	2.75	35.8	47.12	21.98	67.63
1997	26	36.27	11.79	2.31	31.51	41.03	6.2	50.91
1998	26	41.16	12.41	2.43	36.15	46.17	20.13	65.67
1999	26	42.36	17.01	3.34	35.49	49.23	15.64	101.47
2000	26	51.05	23.12	4.53	41.71	60.39	28.99	127.57
Total	234	39.57	15.89	1.04	37.53	41.62	6.2	127.57

Table 14 ANOVA Results of Total Crash Rates in North Carolina by year

		Sum of Squares	df	Mean Square	F	Sig.
TOTALR	Between Groups	7412.9	8	926.61	4.057	0.000
	Within Groups	51391.14	225	228.41		

Table 15 Levene's Test of Homogeneity of Variance Results of Total Crash Rates in North Carolina by year

	Levene Statistic	df1	df2	Sig.
TOTALR	1.788	8	225	0.08

In Table 14 showing the ANOVA results, the F-value given is as high as 4.057, while the Sig. (or P-Value) is only 0.000, which indicates that there are significant differences somewhere among the years from 1991 to 2000 ($\alpha = 5\%$). To locate these differences, a Post-Hoc test was conducted. Since the Levene's test gave a significance 0.080 for the variable TotalR as shown in Table 15, which is greater than 0.05, the significance level, a Tukey test was proper in this situation. The Tukey results are shown in Table 16.

In Table 16, "*"s indicate where significant difference were found. In this case, the significant differences lie in:

- 1991 is less than 2000
- 1992 is less than 2000
- 1994 is less than 2000
- 1997 is less than 2000

This concluded the analysis on Total Crash Rate of North Carolina. The same procedure was applied to the other variables.

Table 16 Tukey test results of Total Crash Rates in North Carolina by year

6	(J) YEAR	Mean Difference (I-J	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1991	1992	-4.1751	4.19161	0.986	-17.3043	8.9541
	1993	-11.7526	4.19161	0.12	-24.8818	1.3766
	1994	-7.9962	4.19161	0.609	-21.1254	5.133
	1995	-11.4795	4.19161	0.14	-24.6087	1.6497
	1997	-6.285	4.19161	0.855	-19.4143	6.8442
	1998	-11.1771	4.19161	0.166	-24.3063	1.9521
	1999	-12.3775	4.19161	0.082	-25.5067	0.7517
	2000	-21.0714	4.19161	0	-34.2006	-7.9422
1992	1991	4.1751	4.19161	0.986	-8.9541	17.3043
	1993	-7.5775	4.19161	0.677	-20.7067	5.5517
	1994	-3.8211	4.19161	0.992	-16.9503	9.3081
	1995	-7.3044	4.19161	0.719	-20.4336	5.8248
	1997	-2.1099	4.19161	1	-15.2392	11.0193
	1998	-7.002	4.19161	0.764	-20.1312	6.1272
	1999	-8.2024	4.19161	0.575	-21.3316	4.9268
	2000	-16.8963	4.19161	0.002	-30.0255	-3.7671
1993	1991	11.7526	4.19161	0.12	-1.3766	24.8818
	1992	7.5775	4.19161	0.677	-5.5517	20.7067
	1994	3.7563	4.19161	0.993	-9.3729	16.8856
	1995	0.2731	4.19161	1	-12.8561	13.4023
	1997	5.4675	4.19161	0.929	-7.6617	18.5968
	1998	0.5755	4.19161	1	-12.5537	13.7047
	1999	-0.625	4.19161	1	-13.7542	12.5043
	2000	-9.3189	4.19161	0.394	-22.4481	3.8104
1994	1991	7.9962	4.19161	0.609	-5.133	21.1254
	1992	3.8211	4.19161	0.992	-9.3081	16.9503
	1993	-3.7563	4.19161	0.993	-16.8856	9.3729
	1995	-3.4833	4.19161	0.996	-16.6125	9.646
	1997	1.7112	4.19161	1	-11.418	14.8404
	1998	-3.1808	4.19161	0.998	-16.3101	9.9484
	1999	-4.3813	4.19161	0.981	-17.5105	8.7479
	2000	-13.0752	4.19161	0.052	-26.2044	0.054
1995	1991	11.4795	4.19161	0.14	-1.6497	24.6087
	1992	7.3044	4.19161	0.719	-5.8248	20.4336
	1993	-0.2731	4.19161	1	-13.4023	12.8561
	1994	3.4833	4.19161	0.996	-9.646	16.6125
	1997	5.1945	4.19161	0.947	-7.9348	18.3237
	1998	0.3024	4.19161	1	-12.8268	13.4316
	1999	-0.898	4.19161	1	-14.0273	12.2312
	2000	-9.5919	4.19161	0.354	-22.7212	3.5373
1997	1991	6.285	4.19161	0.855	-6.8442	19.4143
	1992	2.1099	4.19161	1	-11.0193	15.2392
	1993	-5.4675	4.19161	0.929	-18.5968	7.6617
	1994	-1.7112	4.19161	1	-14.8404	11.418
	1995	-5.1945	4.19161	0.947	-18.3237	7.9348
	1998	-4.892	4.19161	0.962	-18.0213	8.2372
	1999	-6.0925	4.19161	0.875	-19.2217	7.0367
	2000	-14.7864	4.19161	0.015	-27.9156	-1.6572
1998	1991	11.1771	4.19161	0.166	-1.9521	24.3063
	1992	7.002	4.19161	0.764	-6.1272	20.1312
	1993	-0.5755	4.19161	1	-13.7047	12.5537
	1994	3.1808	4.19161	0.998	-9.9484	16.3101
	1995	-0.3024	4.19161	1	-13.4316	12.8268
	1997	4.892	4.19161	0.962	-8.2372	18.0213
	1999	-1.2005	4.19161	1	-14.3297	11.9288
	2000	-9.8944	4.19161	0.311	-23.0236	3.2349
1999	1991	12.3775	4.19161	0.082	-0.7517	25.5067
	1992	8.2024	4.19161	0.575	-4.9268	21.3316
	1993	0.625	4.19161	1	-12.5043	13.7542
	1994	4.3813	4.19161	0.981	-8.7479	17.5105
	1995	0.898	4.19161	1	-12.2312	14.0273
	1997	6.0925	4.19161	0.875	-7.0367	19.2217
	1998	1.2005	4.19161	1	-11.9288	14.3297
	2000	-8.6939	4.19161	0.494	-21.8231	4.4353
2000	1991	21.0714	4.19161	0	7.9422	34.2006
	1992	16.8963	4.19161	0.002	3.7671	30.0255
	1993	9.3189	4.19161	0.394	-3.8104	22.4481
	1994	13.0752	4.19161	0.052	-0.054	26.2044
	1995	9.5919	4.19161	0.354	-3.5373	22.7212
	1997	14.7864	4.19161	0.015	1.6572	27.9156
	1998	9.8944	4.19161	0.311	-3.2349	23.0236
	1999	8.6939	4.19161	0.494	-4.4353	21.8231

4.3.2 Variable 1: Total Crash Rate

For the variable Total Crash Rate in each of the states, yearly means were plotted together for an intuitive observation as shown in Figure 3:

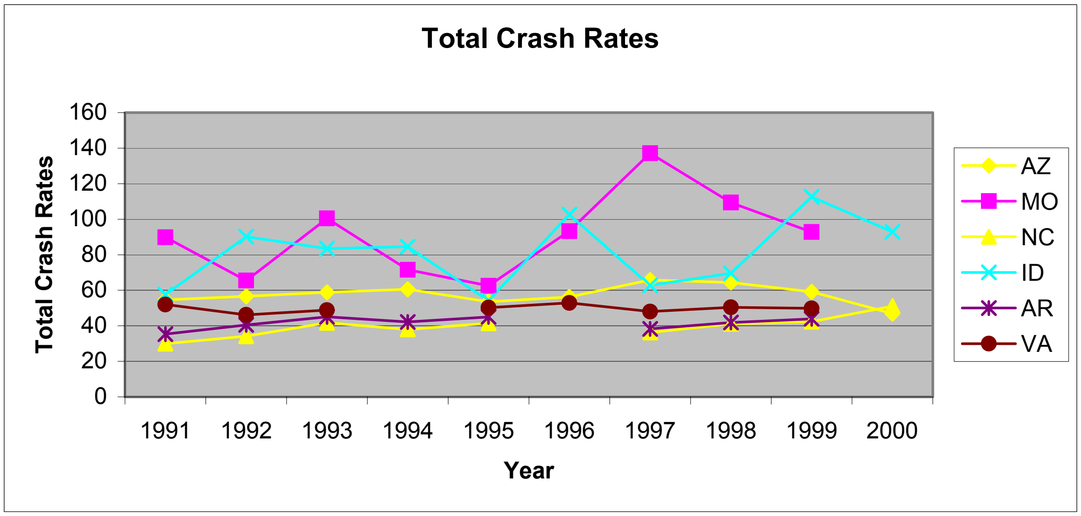

Figure 3 Total Crash Rates in all states (All data)

The final results for all four groups on Total Crash Rate (Total Crash Rate), without after ADT filtering, are shown in Table 17 and Table 18:

Table 17 ANOVA results of Total Crash Rates (All data)

Group	**State**	**Year-pair**		**Before-After**
		ANOVA (F/P)	**Post-Hoc**	**ANOVA (F/P)**
Group 1 (UNI-UNI)	NC	4.057/.000*	#	7.054/.007(+)*
	Arizona	2.266/.016*	#	.301/.583(+)
	Missouri	.320/.948	-	1.610/.218(+)
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	1.027/.418	-	.380/.539(-) 2.080/.153(+)
	Arkansas	.703/.670	-	.007/.935(-)
Group 4 (DSL-UNI)	Virginia	.958/.460	-	.638/.425 (+)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Table 18 Post-Hoc results of Total Crash Rates (All data)

State	Variable	Levene' Sig.	Post-Hoc Test	Result	Note
Arizona	Total Crash Rate	.009	Dunnett	1997>2000, 1998>2000	
NC	Total Crash Rate	.080	Tukey	1991<2000, 1992<2000 1997<2000	

As shown in Table 17, in Group 1 (UNI-UNI), North Carolina showed a significant increase in Total Crash Rate from the Before period to the After period, while

Arizona and Missouri only showed insignificant increases (α = 5%). In yearly comparisons shown in Table 18, Arizona experienced a significant increase from 1997 and 1998 to 2000, and in North Carolina, the Total Crash Rate in 2000 increased greatly, which made it significantly greater than those in 1991, 1992 and 1997.

In Group 3 (UNI-DSL), when the speed limits for Idaho were raised from 104.59/104.59 km/h (65/65 mi/h) to 120.68/120.68 km/h (75/75 mi/h), the Total Crash Rate dropped insignificantly. When the speed limits were changed to 120.68/104.59 km/h (75/65 mi/h), there was an insignificant increase. For Arkansas, the Total Crash Rate shows almost no difference.

In Group 4 (DSL-UNI), Virginia data showed no significant differences in the Total Crash Rates, after the speed limits changed from 104.59/88.50 km/h (65/55 mi/h) to 104.59/104.59 km/h (65/65 mi/h) in 1996.

When the ADT ranges were considered in Total Crash Rate analysis, the results obtained are shown in Table 19 and Table 20. The data are plotted in Figure 4.

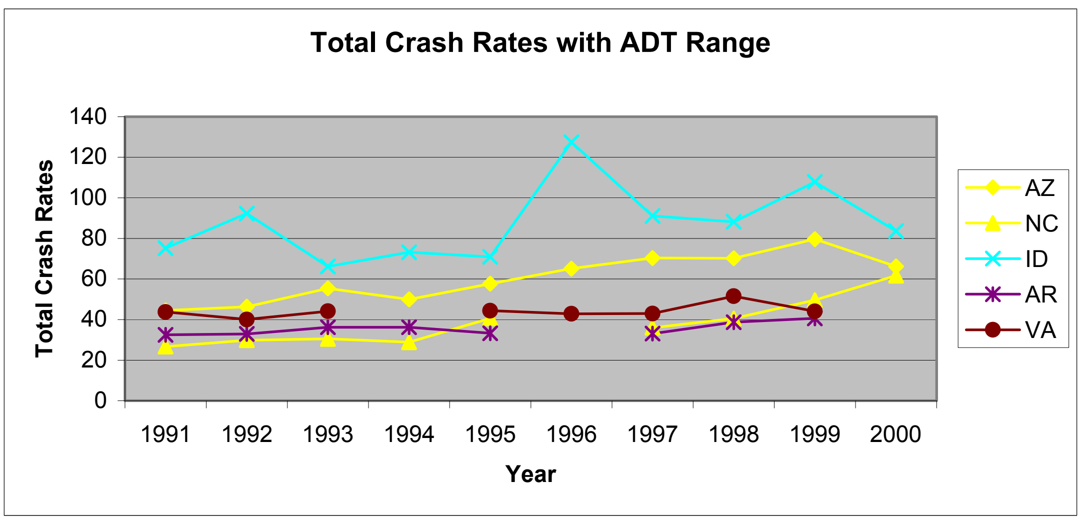

Figure 4 Total Crash Rates in all states (after ADT filtering)

Table 19 ANOVA results of Total Crash Rates (after ADT filtering)

Group	State	Year-pair		Before-After
		ANOVA (F/P)	Post-Hoc	ANOVA (F/P)
Group 1 (UNI-UNI)	NC	3.309/.003*	#	12.737/.001*(+)
	Arizona	3.537/.000*	#	25.127/.000*(+)
	Missouri	N/A	N/A	N/A
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	N/A	N/A	.517/.474(+) .036/.851(+)
	Arkansas	.414/.887	-	.993/.325(+)
Group 4 (DSL-UNI)	Virginia	1.010/.423	-	1.137/.287(+)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Table 20 Post-Hoc results of Total Crash Rates (after ADT filtering)

State	Variable	Levene' Test Significance	Post-Hoc Test	Results	Note
Arizona	Total Crash Rate	.526	Tukey	1991<1999 1992<1999 1994<1999	
NC	Total Crash Rate	.003	Dunnett	No significant difference between pair of years	1991<2000, 1992<2000, 1993<2000, 1994<2000, by Tukey

When comparing Tables 19 and 20 with Tables 17 and 18, in Group 1, after removing the sites with relatively high or low ADT's, the difference found in Arizona between Before and After periods became significant (P< 0.01).

In Group 3, when speed limits for Idaho changed from 104.59/104.59 km/h (65/65 mi/h) to 120.68/120.68 km/h (75/75 mi/h), there was a very slight increase in Total Crash Rate, although not significant. For Arkansas, the change remained very small, almost negligible.

In Group 4, the result is the same for Virginia.

4.3.3 Variable 2: Fatal Crash Rate

Figure 5 shows the plotted Fatal Crash Rates of all the states, and the analyses without considering ADT ranges are presented in Table 21 and Table 22.

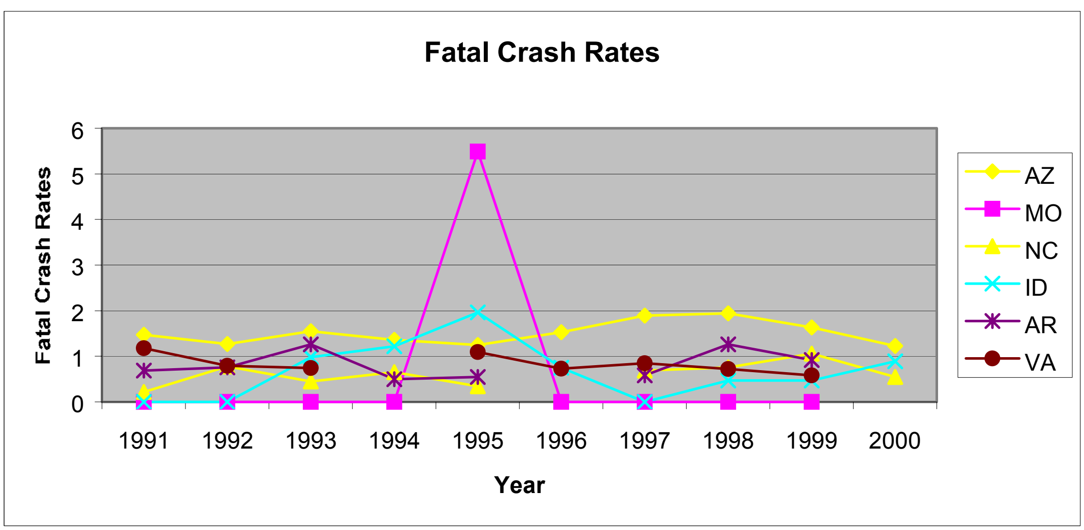

Figure 5 Fatal Crash Rates in all states (All data)

Table 21 ANOVA results of Fatal Crash Rates (All data)

Group	State	Year-pair		Before-After
		ANOVA (F/P)	Post-Hoc	ANOVA (F/P)
Group 1 (UNI-UNI)	NC	1.011/.428	-	2.720/.100(+)
	Arizona	.790/.625	-	2.175/.140(+)
	Missouri	3.453/.014*	#	1.196/.286(-)
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	.841/.579	-	.932/.336(-) 1.732/.192(+)
	Arkansas	.828/.567	-	.470/.495(+)
Group 4 (DSL-UNI)	Virginia	2.344/.022*	#	1.216/.270 (-)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done.
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Table 22 Post-Hoc results of Fatal Crash Rates (All data)

State	Variable	Levene' Sig.	Post-Hoc Test	Result	Note
Missouri	Fatal Crash Rate	.000	Dunnett	1995 > every other years	Only 1995 is not zero
Virginia	Fatal Crash Rate	.000	Dunnett	No significant difference between pair of years	1991>1999 by Tukey

As shown in Table 21, in Group 1, both North Carolina and Arizona did not show any significant difference, either in the yearly or Before-After comparisons. For Missouri, as shown in Table 22, the Fatal Crash Rate in 1995 is significantly greater than any other years. However, two factors should be considered. First, there is no significant difference between the Before and After periods. Second, there were zero fatal crashes for all in both periods except 1995 as shown in Figure 5.

In Group 3, when the speed limits for Idaho was raised from 104.59/104.59 km/h (65/65 mi/h) 65/65 mi/h to 120.68/120.68 km/h (75/75 mi/h), the Fatal Crash Rate dropped slightly, but when the speed limits were changed to 120.68/104.59 km/h (75/65 mi/h), there was an insignificant increase. For Arkansas, the Fatal Crash Rate increased from the Before period to the After period, insignificantly.

In Group 4, after the implement of speed limits change from 104.59/88.50 km/h (65/55 mi/h) to 104.59/104.59 km/h (65/65 mi/h), Virginia experienced an insignificant drop in Fatal Crash Rate.

Figure 6 shows the plotted Fatal Crash Rates of all the states after ADT filtering, and the analysis results are presented in Table 23.

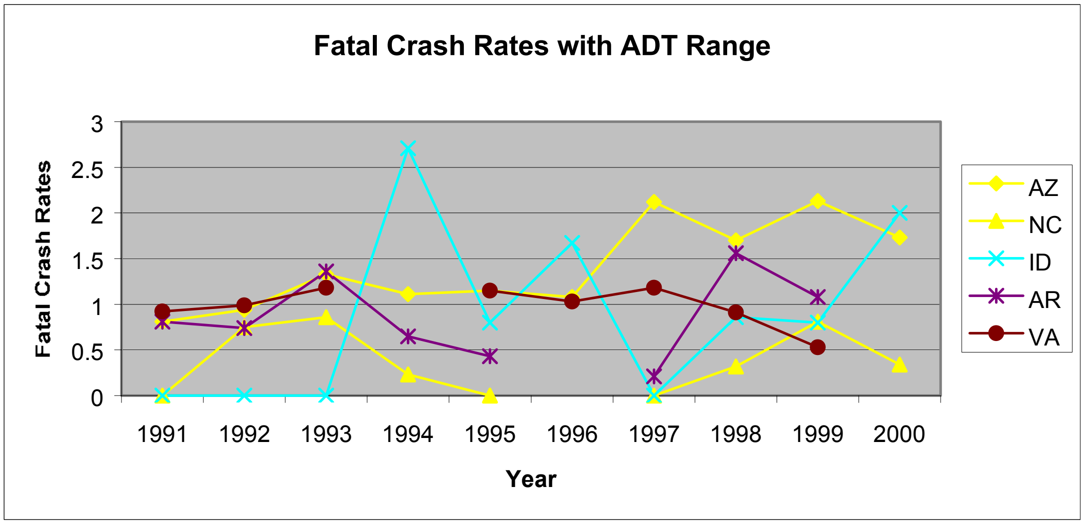

Figure 6 Fatal Crash Rates in all states (after ADT filtering)

Table 23 ANOVA results of Fatal Crash Rates (after ADT filtering)

Group	State	Year-pair		Before-After
		ANOVA (F/P)	**Post-Hoc**	**ANOVA (F/P)**
Group 1 (UNI-UNI)	NC	.795/.609	-	.000/.999(-)
	Arizona	.609/.790	-	3.185/.075(+)
	Missouri	N/A	N/A	N/A
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	N/A	N/A	.308/.581(-) 1.538/.223(+)
	Arkansas	.618/.737	-	.132/.718(+)
Group 4 (DSL-UNI)	Virginia	.746/.633	-	.144/.704(-)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

As shown in Table 23, with ADT ranges filtering, results observed for most of the states were the same as those without ADT filtering. The only difference lies in North Carolina. It shows almost no difference between the Before and After periods (F-Value is 0.000, and P-Value is 0.999).

4.3.4 Variable 3: Rear-end Crash Rate

Figure 7 shows the plotted Rear-End Crash Rates of all the states without considering ADT ranges, and the analyses are presented in Table 24 and Table 25.

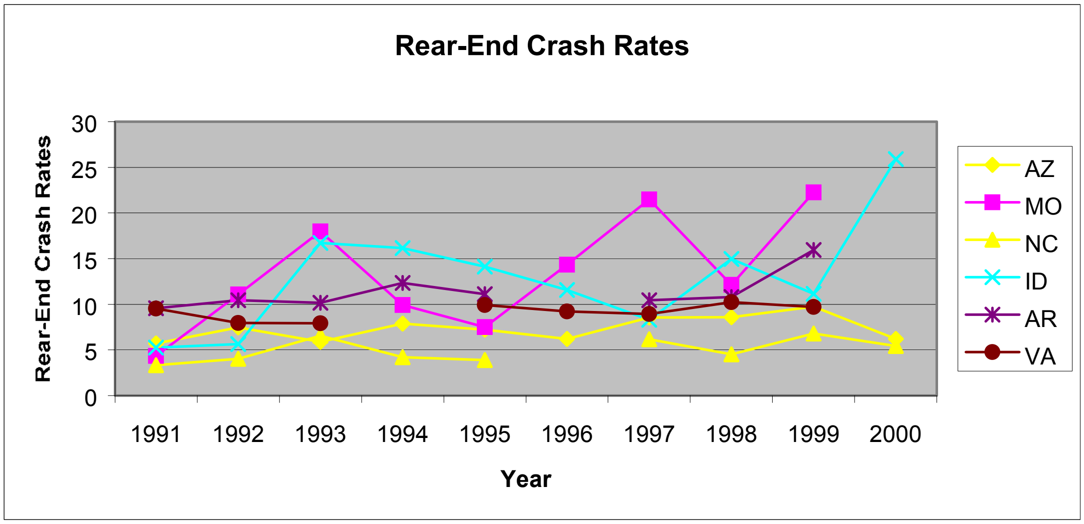

Figure 7 Rear-End Crash Rates in all states (All data)

Table 24 ANOVA results of Rear-End Crash Rates (All data)

Group	**State**	**Year-pair**		**Before-After**
		ANOVA (F/P)	**Post-Hoc**	**ANOVA (F/P)**
Group 1 (UNI-UNI)	NC	1.873/.065	-	4.484/.035(+)*
	Arizona	2.678/.004*	#	3.792/.052(+)
	Missouri	.309/.953	-	1.363/.256(+)
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	.976/.460	-	.379/.539(-) .972/.327(+)
	Arkansas	1.014/.429	-	1.299/.258(+)
Group 4 (DSL-UNI)	Virginia	.757/.624	-	2.433/.119(+)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Table 25 Post-Hoc results of Rear-End Crash Rates (All data)

State	Variable	Levene' Sig.	Post-Hoc Test	Result	Note
Arizona	Rear-end Crash Rate	.000	Dunnett	No significant difference between pair of years	1991<1999, 1993<1999, by Tukey

Rear-End Crash is the most controversial type of crash in DSL studies, since some insist that the Differential Speed Limits tends to create a gap between passenger cars and trucks speeds, which would introduce more crashes as a result.

As shown in Table 24, in Group 1, all of the three states showed increases on Rear-End Crash Rates, but only in North Carolina, was the difference significant. The Post-Hoc comparisons indicate that in Arizona, Rear-End Crash Rates in 1999 were significantly great than those in 1991 and 1993.

In Group 3, when the speed limits for Idaho were raised from 104.59/104.59 km/h (65/65 mi/h) to 120.68/120.68 km/h (75/75 mi/h), the Rear-End Crash Rate dropped slightly, and when the speed limits were changed to 120.68/104.59 km/h (75/65 mi/h), there was an insignificant increase. For Arkansas, the Rear-End Crash Rate insignificantly increased from the Before period to the After period.

In Group 4, Virginia shows a slight increase from Before to After period, but this difference was not found to be significant.

Figure 8 shows the plotted Rear-End Crash Rates of all the states without considering ADT ranges, and the analyses are presented in Table 26 and Table 27.

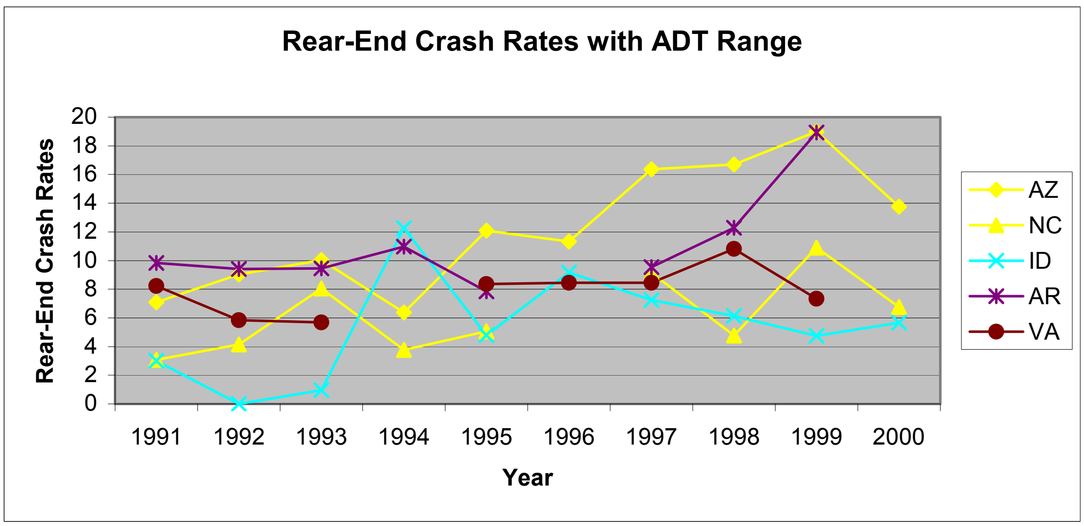

Figure 8 Rear-End Crash Rates in all states (after ADT filtering)

Table 26 ANOVA results of Rear-End Crash Rates (after ADT filtering)

Group	State	Year-pair		Before-After
		ANOVA (F/P)	**Post-Hoc**	**ANOVA (F/P)**
Group 1 (UNI-UNI)	NC	1.526/.166	-	4.382/.040*(+)
	Arizona	3.005/.002*	#	17.610/.000*(+)
	Missouri	N/A	N/A	N/A
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	N/A	N/A	1.177/.281(-) .247/.622(+)
	Arkansas	1.351/.260	-	3.574/.066(+)
Group 4 (DSL-UNI)	Virginia	1.613/.129	-	4.973/.026*(+)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Table 27 Post-Hoc results of Rear-End Crash Rates (after ADT filtering)

State	Variable	Levene' Test Sig.	Post-Hoc Test	Results	Note
Arizona	Rear-end Crash Rate	.174	Tukey	1991<1999, 1994<1999	

Considering the impacts of ADT range, the results are quite different. As shown in Table 26, in Group 1, both North Carolina's and Arizona's increases are significant. In Group 3, for Idaho, the results are same. In Group 4, the increase in Virginia Rear-End Crash Rates became significant.

4.3.5 Variable 4: Total Truck-involved Crash Rate

Figure 9 shows the plotted Rear-End Crash Rates of all the states without considering ADT ranges, and the analyses are presented in Table 28 and Table 29.

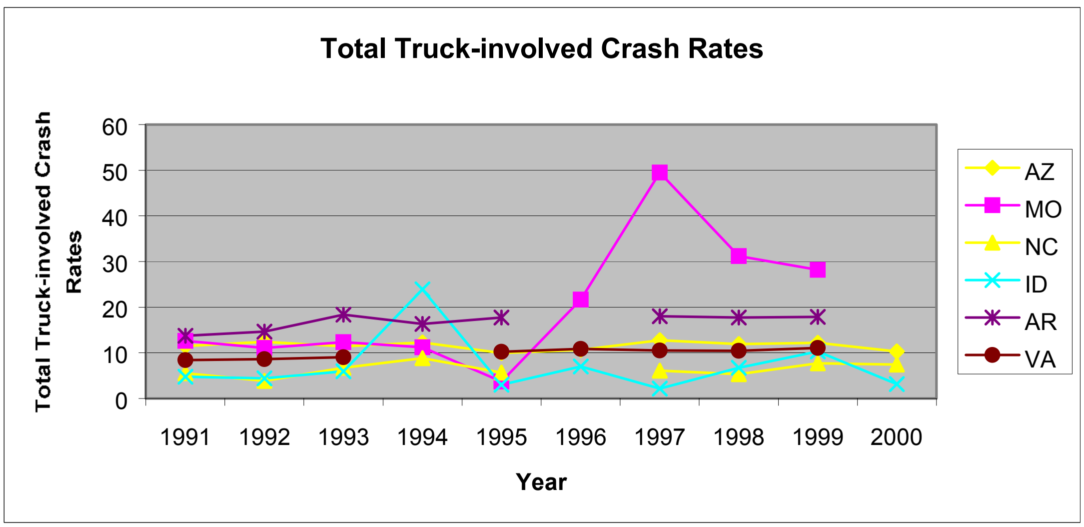

Figure 9 Total Truck-involved Crash Rates in all states (All data)

Table 28 ANOVA results of Truck-involved Crash Rates (All data)

Group	State	Year-pair		Before-After
		ANOVA (F/P)	Post-Hoc	ANOVA (F/P)
Group 1 (UNI-UNI)	NC	1.727/.093	-	.448/.504(+)
	Arizona	.809/.608	-	.004/.949(+)
	Missouri	1.773/.149	-	15.788/.001*(+)
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	1.004/.437	-	.518/.473(-) 2.227/.139(+)
	Arkansas	.701/.671	-	1.342/.250(+)
Group 4 (DSL-UNI)	Virginia	3.471/.001*	#	22.278/.000*(+)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Table 29 Post-Hoc results of Truck-involved Crash Rates (All data)

State	Variable	Levene' Sig.	Post-Hoc Test	Result	Note
Virginia	Total Truck-involved Crash Rate	.306	Tukey	1991<1996, 1991<1999, 1992<1999	

As shown in Table 28, in Group 1, North Carolina and Arizona showed insignificant increases on Total Truck-involved Crash Rate, while in Missouri, where the 3 sites may not represent the real situations fully, its increase is significant (α = 5%).

In Group 3, when the speed limits for Idaho were raised from 104.59/104.59 km/h (65/65 mi/h) to 120.68/120.68 km/h (75/75 mi/h), the Total Truck-involved Crash Rate dropped slightly, and when the speed limits were changed to 120.68/104.59 km/h (75/65 mi/h), there was an insignificant increase. For Arkansas, the Total Truck-involved Crash Rate insignificantly increased from the Before period to the After period.

In Group 4, Virginia experienced a significant increase from the Before period to the After period with a P-value of zero.

Figure 10 shows the plotted Rear-End Crash Rates of all the states without considering ADT ranges, and the analyses are presented in Table 30.

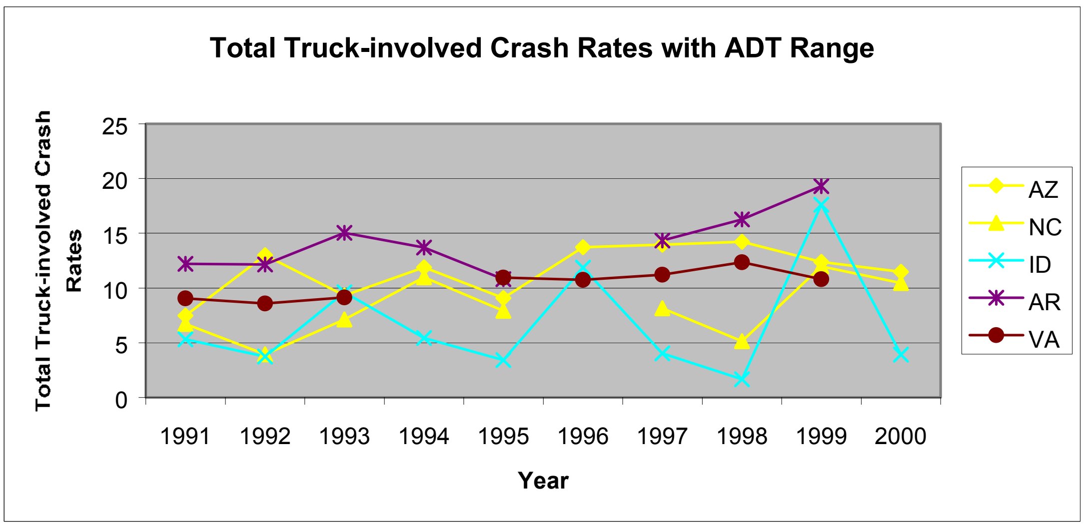

Figure 10 Total Truck-involved Crash Rates in all states (after ADT filtering)

Table 30 ANOVA results of Total Truck-involved Crash Rates (after ADT filtering)

Group	**State**	**Year-pair**		**Before-After**
		ANOVA (F/P)	**Post-Hoc**	**ANOVA (F/P)**
Group 1 (UNI-UNI)	NC	.937/.493	-	.732/.395(+)
	Arizona	1.395/.190	-	5.865/.016*(+)
	Missouri	N/A	N/A	N/A
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	N/A	N/A	.270/.605(-) 1.131/.294(+)
	Arkansas	1.645/.159	-	6.453/.015*(+)
Group 4 (DSL-UNI)	Virginia	1.658/.117	-	9.794/.002*(+)

Note: F/P – F-Ratio and P-Value of ANOVA test,

"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Comparing Table 30 with the results without considering ADT range as shown in Tables 28 and 29, Arizona's increase becomes significant in Group 1, and so did Arkansas's in Group 3, while the differences found in yearly analysis were no longer significant.

4.3.6 Variable 5: Truck-involved Fatal Crash Rate

Figure 11 shows the plotted Rear-End Crash Rates of all the states without considering ADT ranges, and the analyses are presented in Table 31.

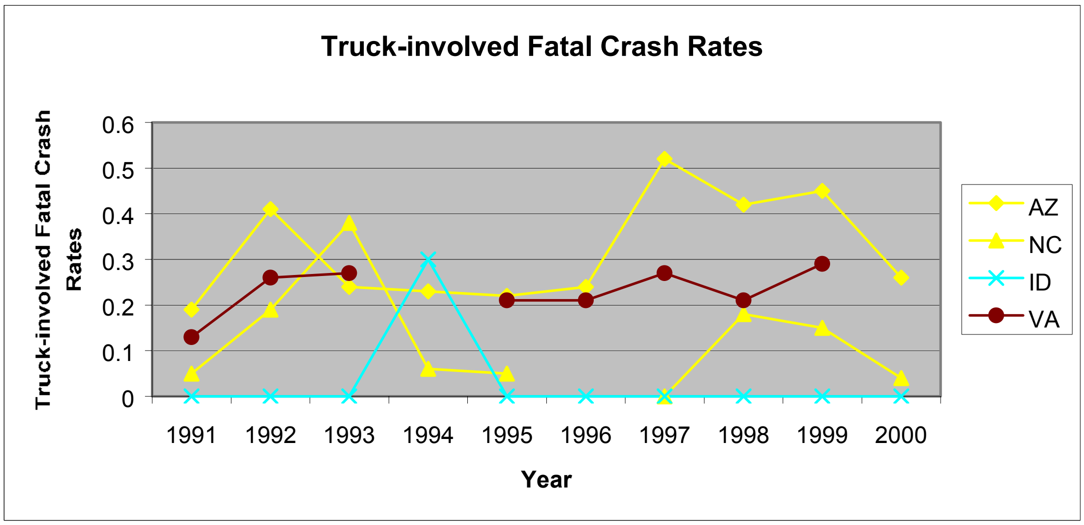

Figure 11 Truck-involved Fatal Crash Rates in all states (All data)

Table 31 ANOVA results of Truck-involved Fatal Crash Rates (All data)

Group	State	Year-pair		Before-After
		ANOVA (F/P)	**Post-Hoc**	**ANOVA (F/P)**
Group 1 (UNI-UNI)	NC	.917/.503	-	.405/.525(-)
	Arizona	.899/.525	-	2.248/.134(+)
	Missouri	N/A	N/A	N/A
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	1.000/.440	-	.199/.656(-) All Zeros
	Arkansas	N/A	N/A	N/A
Group 4 (DSL-UNI)	Virginia	.705/.668	-	.188/.665(+)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

As shown in Table 31, in Group 1, North Carolina showed an insignificant decrease in Truck-involved Fatal Crash Rate, while Arizona also showed an insignificant increase.

In Group 3, for Idaho, since no Truck-involved Fatal Crashes happened after 1994, the crash rates decreased.

In Group 4, Virginia showed an insignificant increase.

Figure 12 shows the plotted Rear-End Crash Rates of all the states with considering ADT ranges, and the analyses are presented in Table 32.

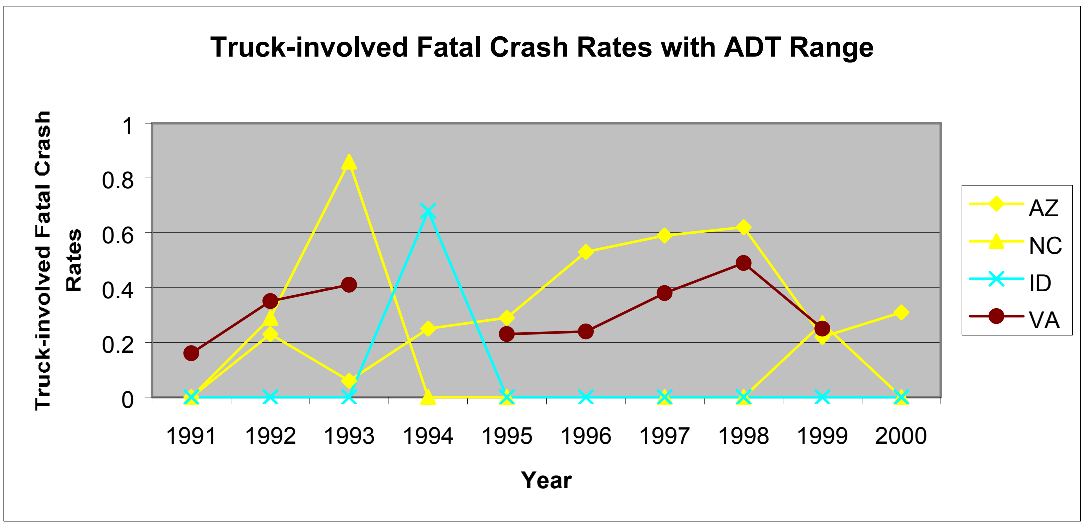

Figure 12 Truck-involved Fatal Crash Rates in all states (after ADT filtering)

Table 32 ANOVA results of Truck-involved Fatal Crash Rates (after ADT filtering)

Group	State	Year-pair		Before-After
		ANOVA (F/P)	Post-Hoc	ANOVA (F/P)
Group 1 (UNI-UNI)	NC	.843/.568	-	.585/.447(-)
	Arizona	.862/.560	-	4.077/.044*(+)
	Missouri	N/A	N/A	N/A
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	N/A	N/A	.198/.658(-) All zeroes
	Arkansas	N/A	N/A	N/A
Group 4 (DSL-UNI)	Virginia	.744/.635	-	.018/.894(+)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Comparing Table 31 and Table 32, the only difference lies in Arizona's increase, which became significant when considering ADT Ranges.

4.3.7 Variable 6: Truck-involved Rear-end Crash Rate

Figure 13 shows the plotted Rear-End Crash Rates of all the states without considering ADT ranges, and the analysis results are presented in Table 33.

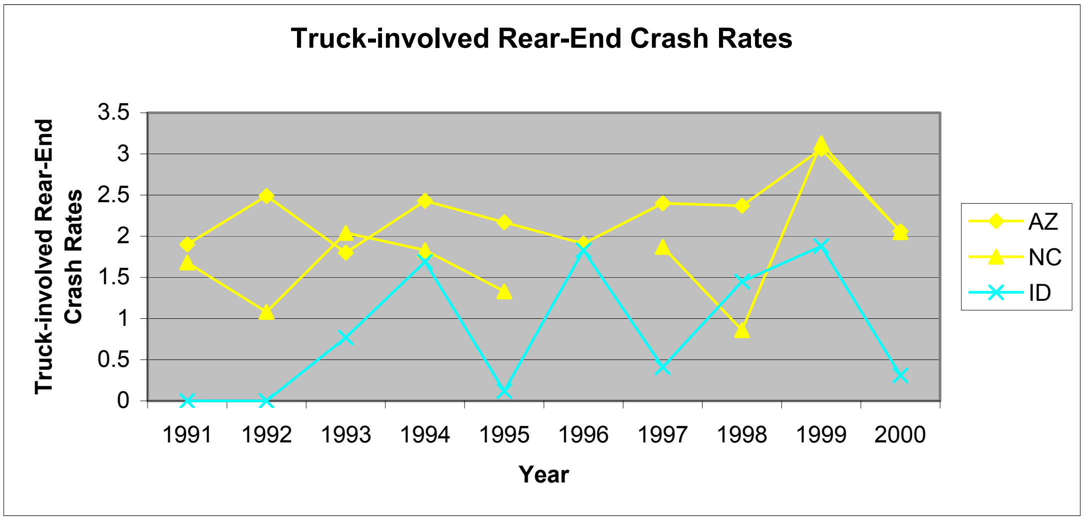

Figure 13 Truck-involved Rear-End Crash Rates in all states (All data)

As shown in Table 33, in Group 1, Both North Carolina and Arizona showed insignificant increases on Truck-involved Rear-End Crash Rate.

Table 33 ANOVA results of Truck-involved Rear-End Crash Rates (All data)

Group	**State**	**Year-pair**		**Before-After**
		ANOVA (F/P)	**Post-Hoc**	**ANOVA (F/P)**
Group 1 (UNI-UNI)	NC	1.099/.365	-	.822/.366(+)
	Arizona	.943/.486	-	.690/.406(+)
	Missouri	N/A	N/A	N/A
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	1.519/.141	-	.052/.820(-) .811/.370(+)
	Arkansas	N/A	N/A	N/A
Group 4 (DSL-UNI)	Virginia	N/A	N/A	N/A

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

In Group 3, when the speed limits for Idaho was raised from 104.59/104.59 km/h (65/65 mi/h) to 120.68/120.68 km/h (75/75 mi/h), the Total Truck-involved Crash Rate dropped slightly, but when the speed limits were changed to 120.68/104.59 km/h (75/65 mi/h), there was an insignificant increase.

Figure 14 shows the plotted Rear-End Crash Rates of all the states with considering ADT ranges, and the analysis are presented in Table 34.

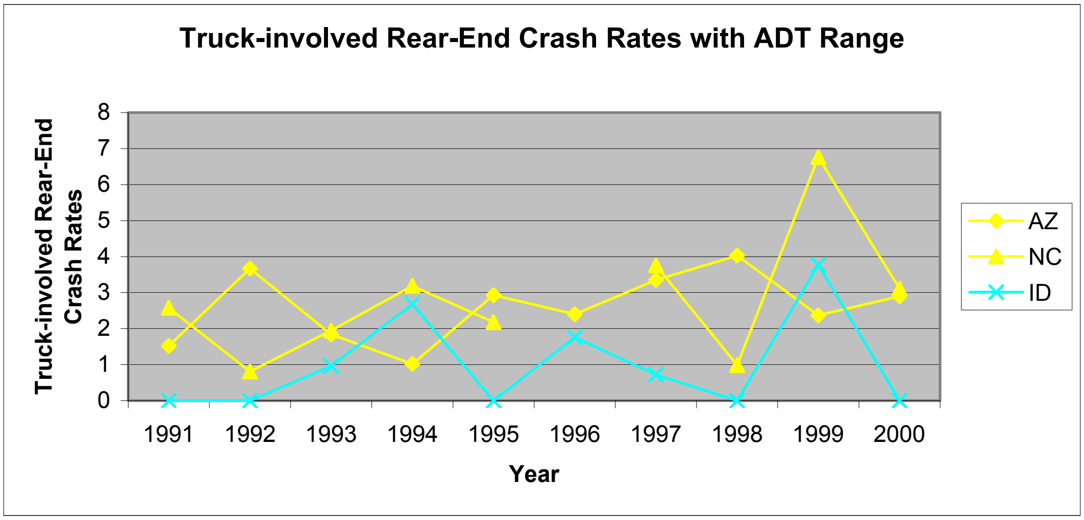

Figure 14 Truck-involved Rear-End Crash Rates in all states (after ADT filtering)

Table 34 ANOVA results of Truck-involved Rear-End Crash Rates (after ADT filtering)

Group	State	Year-pair		Before-After
		ANOVA (F/P)	Post-Hoc	ANOVA (F/P)
Group 1 (UNI-UNI)	NC	1.016/.433	-	1.656/.202(+)
	Arizona	1.688/.091	-	2.993/.085(+)
	Missouri	N/A	N/A	N/A
Group 2 (DSL-DSL)	N/A			
Group 3 (UNI-DSL)	Idaho	N/A	N/A	.000/.994(-) .516/.477(+)
	Arkansas	N/A	N/A	N/A
Group 4 (DSL-UNI)	Virginia	N/A	N/A	N/A

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

The results considering ADT ranges shown in Table 34 are the same as those without considering ADT ranges in Table 33.

4.3.8 Analysis on individual Interstates in Virginia

In Virginia, a state in Group 4, data from five major Interstate highways, namely I-64, I-77, I-81, I-85 and I-95 were available. This made it possible to do a detailed crash analysis for each of them. The analysis results are shown in Table 35 and Table 36. Those two tables show the same results, but in a different sorting manner, Table 35 by variable and Table 36 by Interstate highway, in order to make it convenient to compare the results both ways. The Post-Hoc comparisons for certain variables are shown in Table 37. The variables are plotted in from Figure 15 to Figure 19.

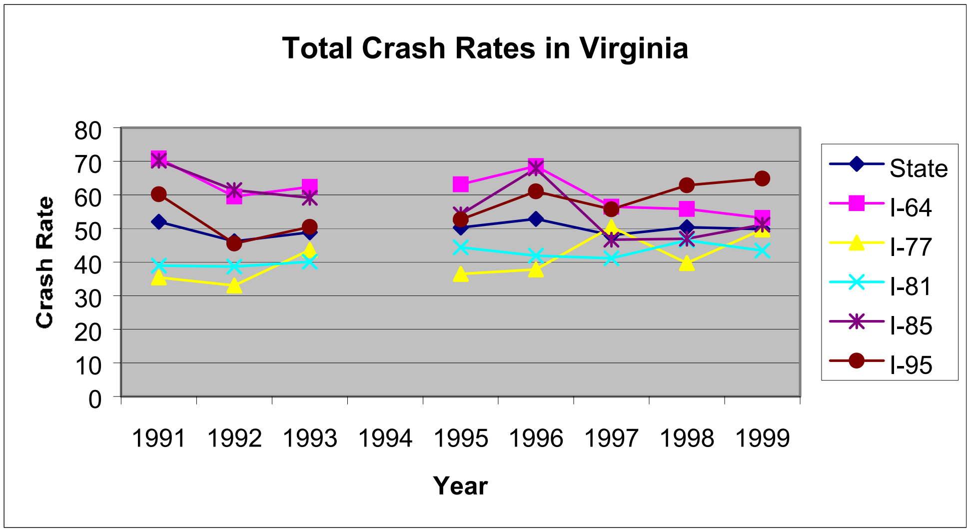

Figure 15 Total Crash Rates in Virginia Interstate Highways (All data)

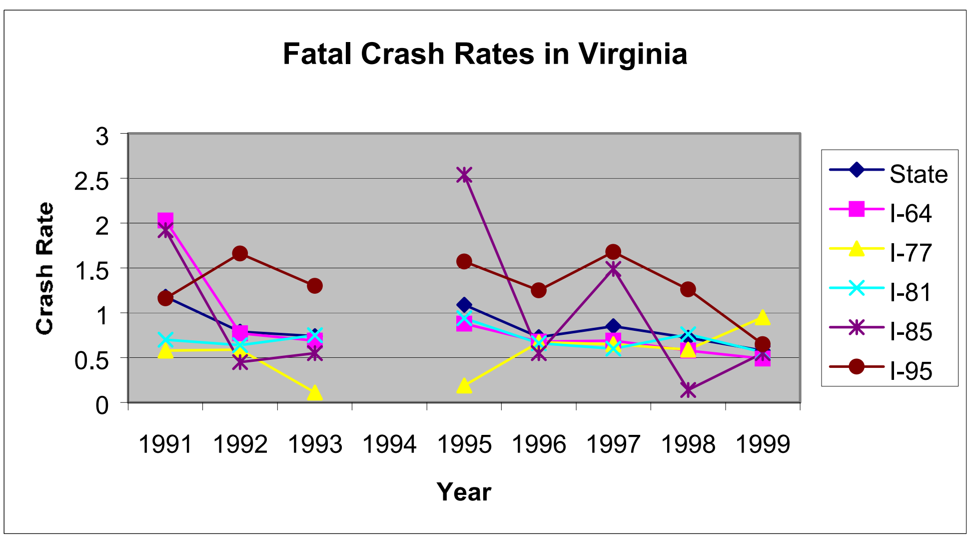

Figure 16 Fatal Crash Rates in Virginia Interstate Highways (All data)

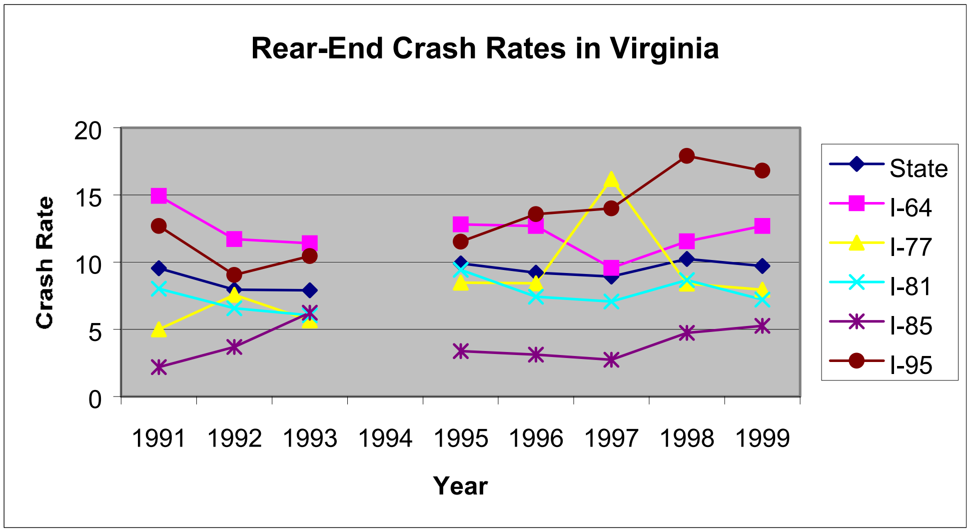

Figure 17 Rear-End Crash Rates in Virginia Interstate Highways (All data)

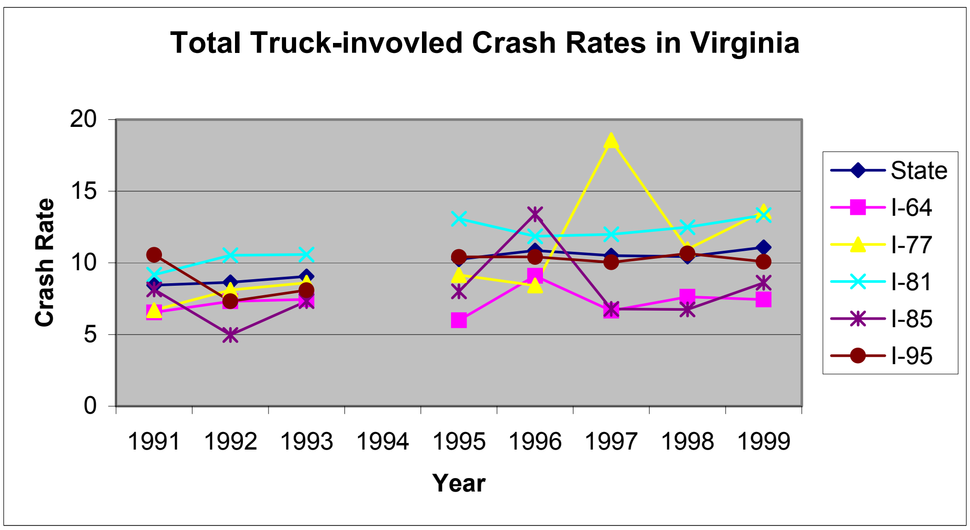

Figure 18 Total Truck-involved Crash Rates in Virginia Interstate Highways (All data)

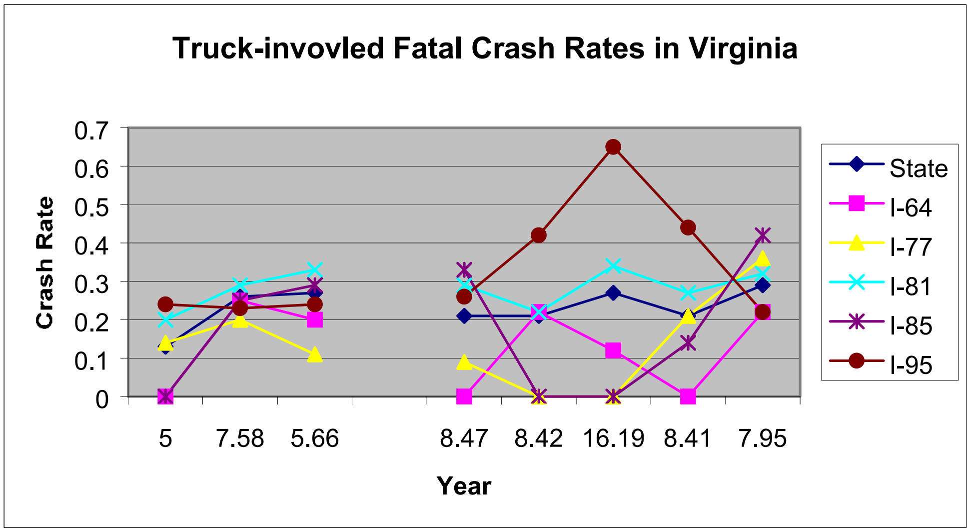

Figure 19 Truck-involved Fatal Crash Rates in Virginia Interstate Highways (All data)

Among these five Interstate highways, I-81 is somehow different from the others. The reason is that the daily traffic volumes in some areas have doubled in the recent years up to more than 50,000 vehicles, and trucks now account for 20 percent to 40 percent of the traffic[9]. To exclude the potential impacts of the special features of I-81, an analysis on crash rates without I-81 was conducted on Virginia data. The results are shown in Table 38.

Note that while significant difference were obtained for fatal crash rate and total truck-involved crash rate when using all Virginia data, the difference were not significant when I-81 was excluded. This indicates that I-81 had significant influence on the analysis for the whole state of Virginia.

Table 35 Crash Analysis on individual Interstates in Virginia (All data), sorted by variable

Interstate	# of Sites	Variable	Year-pair ANOVA (F/P)	Before-After ANOVA (F/P)
State	267	Total Crash Rate	.958/.460	.638/.425(+)
I-64	64	Total Crash Rate	.961/.459	1.094/.296(-)
I-77	21	Total Crash Rate	1.151/.334	1.519/.220(+)
I-81	122	Total Crash Rate	2.044/.047*	9.198/.002(+)*
I-85	24	Total Crash Rate	2.449/.020*	5.788/.017(-)*
I-95	36	Total Crash Rate	.918/.493	2.060/.152(+)
State	267	Fatal Crash Rate	2.344/.022*	1.216/.270(-)
I-64	64	Fatal Crash Rate	1.972/.057	3.805/.052(-)
I-77	21	Fatal Crash Rate	.727/.650	.605/.438(+)
I-81	122	Fatal Crash Rate	.647/.717	.006/.936(+)
I-85	24	Fatal Crash Rate	2.811/.008*	.047/.829(+)
I-95	36	Fatal Crash Rate	.721/.654	.103/.749(-)
State	267	Rear-End Crash Rate	.757/.624	2.433/.119(+)
I-64	64	Rear-End Crash Rate	.214/.982	.116/.733(-)
I-77	21	Rear-End Crash Rate	1.603/.138	3.754/.054(+)
I-81	122	Rear-End Crash Rate	2.033/.048*	3.668/.056(+)
I-85	24	Rear-End Crash Rate	1.696/.112	.060/.807(-)
I-95	36	Rear-End Crash Rate	1.159/.326	3.917/.049(+)*
State	267	Total Truck-involved Crash Rate	3.471/.001*	22.278/.000(+)*
I-64	64	Total Truck-involved Crash Rate	.637/.725	.092/.762(+)
I-77	21	Total Truck-involved Crash Rate	2.373/.025*	5.420/.021(+)*
I-81	122	Total Truck-involved Crash Rate	3.958/.000*	21.949/.000(+)*
I-85	24	Total Truck-involved Crash Rate	1.899/.072	2.065/.152(+)
I-95	36	Total Truck-involved Crash Rate	.625/.735	2.060/.152(+)
State	267	Truck-involved Fatal Crash Rate	.705/.668	.188/.665(+)
I-64	64	Truck-involved Fatal Crash Rate	.842/.552	.203/.653(-)
I-77	21	Truck-involved Fatal Crash Rate	.702/.670	.020/.888(-)
I-81	122	Truck-involved Fatal Crash Rate	.296/.956	.074/.786(+)
I-85	24	Truck-involved Fatal Crash Rate	.725/.651	.001/.974(-)
I-95	36	Truck-involved Fatal Crash Rate	.635/.727	1.345/.247(+)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done.

Table 36 Crash Analysis in Virginia Interstates (All data), sorted by Interstate highway

Interstate	# of Sites	Variable	Year-pair ANOVA	Before-After ANOVA (F/P)
I-64	64	Total Crash Rate	.961/.459	1.094/.296(-)
I-64	64	Fatal Crash Rate	1.972/.057	3.805/.052(-)
I-64	64	Rear-End Crash Rate	.214/.982	.116/.733(-)
I-64	64	Total Truck-involved Crash Rate	.637/.725	.092/.762(+)
I-64	64	Truck-involved Fatal Crash Rate	.842/.552	.203/.653(-)
I-77	21	Total Crash Rate	1.151/.334	1.519/.220(+)
I-77	21	Fatal Crash Rate	.727/.650	.605/.438(+)
I-77	21	Rear-End Crash Rate	1.603/.138	3.754/.054(+)
I-77	21	Total Truck-involved Crash Rate	2.373/.025*	5.420/.021(+)*
I-77	21	Truck-involved Fatal Crash Rate	.702/.670	.020/.888(-)
I-81	122	Total Crash Rate	2.044/.047*	9.198/.002(+)*
I-81	122	Fatal Crash Rate	.647/.717	.006/.936(+)
I-81	122	Rear-End Crash Rate	2.033/.048*	3.668/.056(+)
I-81	122	Total Truck-involved Crash Rate	3.958/.000*	21.949/.000(+)
I-81	122	Truck-involved Fatal Crash Rate	.296/.956	.074/.786(+)
I-85	24	Total Crash Rate	2.449/.020*	5.788/.017(-)*
I-85	24	Fatal Crash Rate	2.811/.008*	.047/.829(+)
I-85	24	Rear-End Crash Rate	1.696/.112	.060/.807(-)
I-85	24	Total Truck-involved Crash Rate	1.899/.072	2.065/.152(+)
I-85	24	Truck-involved Fatal Crash Rate	.725/.651	.001/.974(-)
I-95	36	Total Crash Rate	.918/.493	2.060/.152(+)
I-95	36	Fatal Crash Rate	.721/.654	.103/.749(-)
I-95	36	Rear-End Crash Rate	1.159/.326	3.917/.049(+)*
I-95	36	Total Truck-involved Crash Rate	.625/.735	2.060/.152(+)
I-95	36	Truck-involved Fatal Crash Rate	.635/.727	1.345/.247(+)
State	267	Total Crash Rate	.958/.460	.638/.425(+)
State	267	Fatal Crash Rate	2.344/.022*	1.216/.270(-)
State	267	Rear-End Crash Rate	.757/.624	2.433/.119(+)
State	267	Total Truck-involved Crash Rate	3.471/.001*	22.278/.000(+)
State	267	Truck-involved Fatal Crash Rate	.705/.668	.188/.665(+)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done.

Table 37 Post-Hoc results of all variables in Virginia Interstate Highways (All data)

Interstate	Variable	Levene' Sig.	Post-Hoc Test	Results	Note
State	Fatal Crash Rate	.000	Dunnett	No significant difference between pair of years	1991>1999 by Tukey
	Total Crash Rate	.306	Tukey	1991<1996 1991<1999 1992<1999	
77	Total Crash Rate	.035	Dunnett	No significant difference between pair of years	1991<1997 by Tukey
81	Total Crash Rate	.522	Tukey	1992<1998	
	Rear-end Crash Rate	.020	Dunnett	No significant difference between pair of years	1993<1995 by Tukey
	Total Crash Rate	.043	Dunnett	1991<1995, 1991<1998, 1991<1999	
85	Total Crash Rate	.003	Dunnett	No significant difference between pair of years	
	Fatal Crash Rate	.000	Dunnett	No significant difference between pair of years	1995>1998 by Tukey

Table 38 ANOVA results of Crash Rates in Virginia excluding I-81

Interstate	# of Site	Variable	Year-pair		Before-After
			ANOVA (F/P)	Post-Hoc	ANOVA (F/P)
State	267	TCR	1.859/.074	-	.069/.793(+)
State	267	FCR	.908/.500	-	.858/.355(-)
State	267	RECR	1.684/.111	-	4.641/.032(+)*
State	267	TTCR	1.380/.212	-	7.814/.005(+)*
State	267	TFCR	.472/.855	-	.247/.620(-)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done.

4.3.9 Summary of Crash Analysis Results

Based on the results shown in Table 36 and Table 37, the analysis on each variable can be summarized as follows:

Variable 1 Total Crash Rate

The variable Total Crash Rate does not show any regular trends among the Interstate highways. A significant increase was found on I-81, while a significant decrease was seen on I-85. Other Interstates show either significant increases (I-77 and I-95) or decrease (I-64). The overall effect on the whole state is an insignificant increase.

Variable 2 Fatal Crash Rate

For all of the Interstates, Fatal Crash Rate does not show any significant change, although some of the Interstates experienced increases (I-77, I-81 and I-85), and others experienced decreases (I-64 and I-95).

Variable 3 Rear-end Crash Rate

Similar to Fatal Crash Rate, the trend of Rear-End Crash Rate also varied with the individual Interstate highways. The only significant increase was found on I-95, which does not affect the insignificant change for the whole state of Virginia.

Variable 4 Total Truck-involved Crash Rate

Although consistent increases were observed for total truck-involved crash rate, these increases were not statistically significant in some cases.

Variable 5 Truck-involved Fatal Crash Rate

Similar to variable Fatal Crash Rate, this Truck-involved Fatal Crash Rate does not show any significant changes in the individual Interstates, or for the whole state.

4.4 Conclusions and Discussions

Results of the Before-After analysis for the four groups are summarized in Table 39.

Table 39 Summary of Before-After comparison results for 4 groups

Group	State	Variable	Before-After Analysis Result			
			Without ADT		With ADT	
			Difference	Significant	Difference	Significant
1	AZ	TCR	+	N	+	Y
		FCR	+	N	+	N
		RECR	+	N	+	Y
		TTCR	+	N	+	Y
		TFCR	+	N	+	Y
		TRECR	+	N	+	N
	MO	TCR	+	N		
		FCR	-	N		
		RECR	+	N		
		TTCR	+	Y		
		TFCR				
		TRECR				
	NC	TCR	+	Y	+	Y
		FCR	+	N	-	N
		RECR	+	Y	+	Y
		TTCR	+	N	+	N
		TFCR	-	N	-	N
		TRECR	+	N	+	N
2						
3	AR	TCR	-	N	+	N
		FCR	+	N	+	N
		RECR	+	N	+	N
		TTCR	+	N	+	Y
		TFCR				
		TRECR				
	ID	TCR	-, +	N, N	+, +	N, N
		FCR	-, +	N, N	-, +	N, N
		RECR	-, +	N, N	-, +	N, N
		TTCR	-, +	N, N	-, +	N, N
		TFCR	-, 0	N, N	-, 0	N, N
		TRECR	-, +	N, N	-, +	N, N
4	VA	TCR	+	N	+	N
		FCR	-	N	-	N
		RECR	+	N	+	Y
		TTCR	+	Y	+	Y
		TFCR	+	N	+	N
		TRECR				

Note: "+" – Variable increased from the Before to the After period
"-" – Variable decreased from the Before to the After period
"N" – The difference is NOT significant ($\alpha = 5\%$)
"Y" – The difference is significant ($\alpha = 5\%$)

Based the results shown in Section 4.3, some conclusions could be drawn:

Analysis of Groups:

- After comparing the analysis results from each Group, no obviously consistent changing trend in Crash Rates was found, which could be accounted for by implementation of DSL or uniform speed limits for passenger cars and trucks. Although the DSL or uniform speed limits would possibly have impacts on the Crash Rates to some extent, some other unknown factors played important roles as well, which made the potential impacts of DSL or uniform speed limits less dominant.

- The using of ADT filtering caused big changes in the analysis results in some cases. The explanation for this could be that when the impacts of ADT's on crash rates are not considered, those impacts tend to mitigate each other among high-ADT sites and low-ADT sites. By removing the sites with too-high or too-low ADT's from the data, the impacts of ADT's became less significant and the impacts of speed limits policies become more clear. Based on this acknowledge, the analysis results that consider ADT would be more meaningful in this study.
- For Total Crash Rate, the control Group 1 showed significant increase throughout the 1990's. Meanwhile, Group 3 (UNI-DSL) and Group 4 (DSL-UNI) both showed insignificant raises.
- For Fatal Crash Rate, all of the groups showed insignificant changes.
- For Rear-End Crash Rate, the control Group 1 showed a significant increase. Group 3 did not show any significant change. Group 4 experienced significant increase, after the speed limits were changed from DSL to UNI.
- For Total Truck-involved Crash Rate, all of the groups showed increases, and in each group, there was one state whose increase was significant.
- For Truck-involved Fatal Crash Rate, in the control group, North Carolina's slight drop could be accounted for by the speed limits' raise from 104.59/104.59 km/h (65/65 mi/h) to 112.63/112.63 km/h (70/70 mi/h). While Arizona kept the same speed limits, it showed a significant increase. In Group 2, Idaho's Truck-involved Fatal Crash Rate dropped slight as well, as in North Carolina, when it raised speed limits from 104.59/104.59 km/h (65/65 mi/h) to 120.68/120.68 km/h (75/75 mi/h). In Group 4, the transfer from DSL of 104.59/88.50 km/h (65/55 mi/h) did not cause a significant change in Truck-involved Fatal Crash Rate.
- For Truck-involved Rear-End Crash Rate, in both Groups 1 and 3, no significant changes were found.

Analysis in Virginia:

- No obviously consistent changing trend in Crash Rates was found over all the Interstates highways in Virginia, which could be accounted for merely by implementation of changing speed limits.
- The only significant change that happened to the whole state was an increase of Total Truck-involved Crash Rate.

Chapter 5 Speed Data Analysis

In this chapter, five selected variables were analyzed and discussed. These are: Mean Speed, Speed Variance, 85th Percentile Speed, Median Speed, and Noncompliance. All of these variables are for all vehicles. In speed analysis, the methodology is similar to the procedures applied in crash analysis shown in Chapter 4. The only difference is that all analyses in this chapter take ADT ranges into consideration, in order to reduce the traffic volume's impacts on speed distribution as much as possible.

5.1 Groups Information

Table 40 shows the grouping of all states, which were employed in this study. Among the nine states, five had speed data available, namely Iowa, Illinois, Indiana, Idaho and Virginia.

Table 40 Summary of four groups

	Grouping	Data Availability	
Group 1: (UNI-UNI)	**Speed Limit Changes**	Crash Rate	Speed
AZ	Always 120.68/120.68 km/h (75/75 mi/h)	Y	N
IA	Always 104.59/104.59 km/h (65/65 mi/h)	N	Y
MO	88.50/88.50 km/h (55/55 mi/h) → 112.63/112.63 km/h (70/70 mi/h), 1996	Y	N
NC	104.59/104.59 km/h (65/65 mi/h) → 112.63/112.63 km/h (70/70 mi/h), 1996	Y	N
Group 2: (DSL-DSL)	**Speed Limit Changes**		
IL	Always 112.63/104.59 km/h (70/65 mi/h)	N	Y
IN	Always 104.59/96.54 km/h (65/60 mi/h)	N	Y
Group 3: (UNI-DSL)	**Speed Limit Changes**		
AR	104.59/104.59 km/h (65/65 mi/h) → 112.63/104.59 km/h (70/65 mi/h), Aug 1996	Y	N
ID	104.59/104.59 km/h (65/65 mi/h) → 120.68/120.68 km/h (75/75 mi/h) → 120.68/104.59 km/h (75/65 mi/h), May 1996 and July 1998	Y	Y
Group 4: (DSL-UNI)	**Speed Limit Changes**		
VA	104.59/88.50 km/h (65/55 mi/h) → 104.59/104.59 km/h (65/65 mi/h), July 1994	Y	Y

Each group involved in speed analysis is given brief introduction below.

Group 1 (UNI-UNI) contains Iowa, which kept a uniform speed limit of 104.59/104.59 km/h (65/65 mi/h) for both passenger cars and trucks.

Group 2 (DSL-DSL) includes those states that kept DSL throughout 1990's. The two states in this group are Illinois and Indiana, the former state kept 112.63/104.59 km/h (70/65 mi/h) and the latter maintained 104.59/96.54 km/h (65/60 mi/h).

Group 3 (UNI-DSL) includes the state of Idaho. Idaho changed its speed limits twice. In May 1996, speed limits for passenger cars and trucks were raised by the same extent from 104.59 km/h (65 mi/h) to 120.68 km/h (75 mi/h), which resulted a uniform

120.68/120.68 km/h (75/75 mi/h). Then in July 1998, trucks' speed limit was decreased to 104.59 km/h (65 mi/h), which resulted a DSL finally.

Group 4 (DSL-UNI) only contains Virginia, which raised speed limits from 104.59/88.50 km/h (65/55 mi/h) to 104.59/104.59 km/h (65/65 mi/h) in July 1994.

5.2 Data Summary

The data after reduction are summarized as shown in Table 41:

In speed data, the numbers of sites are not the same all through the years in certain states. This is why some ranges are given in the column "# of Site" of Table 41.

Table 41 Summary of Speed data

Group	State	Speed Data Availability					# of Sites	Years of Data
		Mean Speed	Speed Variance	85th Pencentile Speed	Median Speed	Noncompliance		
1	IA	x	NA	NA	NA	NA	1 -- 27	1991 - 2000
2	IL	x	x	x	x	x	4	1993, 1994, 1997 - 1999
	IN	x	NA	x	x	NA	4, 3	1991, 2000
3	ID	x	NA	x	NA	NA	24 -- 38	1991 - 1999
4	VA	x	x	x	x	x	3 -- 7	1991, 1993, 1995, 2000, 2001

Note: "x" indicates that the correspondent data are available, and

5.3 Speed Analysis Results

In this section, the results of the Speed Analysis are presented by variable.

5.3.1 Variable 1: Mean Speed for All Vehicles

Figure 20shows the plotted Mean Speed of all the states, and the analysis results are presented in Table 42 and Table 43.

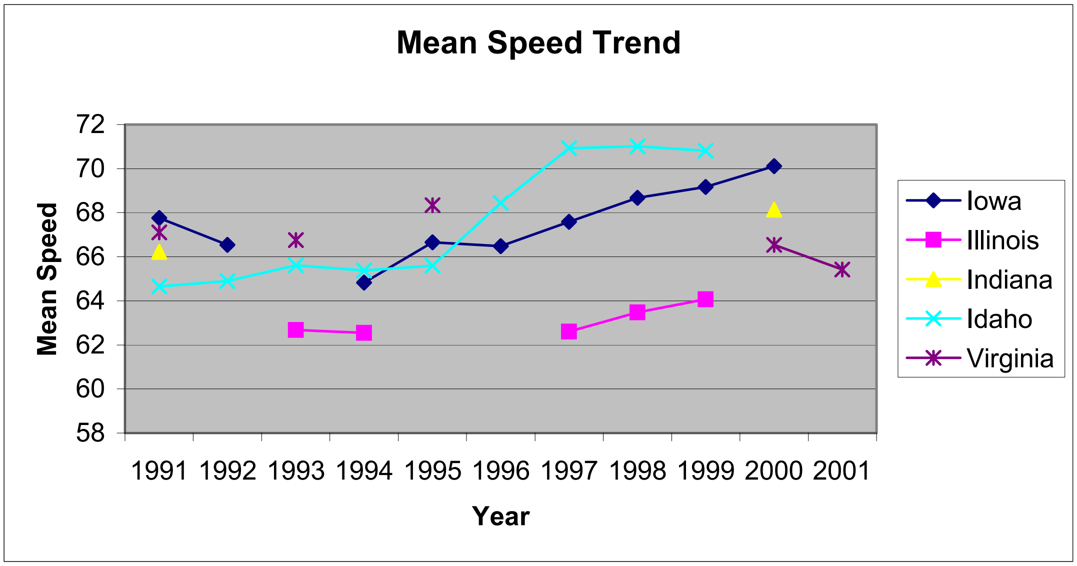

Figure 20 Mean Speed for all vehicles in all states

Table 42 ANOVA results of Mean Speed

Group	State	Year-pair		Before-After
		ANOVA(F/P)	Post-Hoc	ANOVA(F/P)
Group 1 (UNI-UNI)	IA	5.172/.000*	#	14.640/.000*(+)
Group 2 (DSL-DSL)	IL	.195/.937	-	.245/.626(+)
	IN	N/A	N/A	.438/.537(+)
Group 3 (UNI-DSL)	ID	61.894/.000*	#	258.874/.000* (+) .071/.790(-)
Group 4 (DSL-UNI)	VA	2.978/.042*	#	.025/.877(+)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Table 43 Post-Hoc results of Mean Speed

State	Variable	Levene' Sig.	Post-Hoc Test	Results	Note
IA	Mean Speed	.000	Dunnett	1995<2000, 1996<2000, 1997<2000	
ID	Mean Speed	.000	Dunnett	1991<1996, 1992<1996, 1993<1996, 1994<1996, 1995<1996, 1996<1997, 1996<1998, 1996<1999	
VA	Mean Speed	.004	Dunnett	1995>2001	

As shown in Figure 20 and Table 42, in Group 1, Iowa endured a significant increase in the Mean Speed of all vehicles on its Interstate highways, from the Before period [106.7 km/h (66.3 mi/h)] to the After period [110.3 km/h (68.53 mi/h)]. Furthermore, yearly Post-Hoc comparison results in Table 43 obviously suggest that the mean speed in 2000 [112.8 km/h (70.11 mi/h)] was significantly greater than those in 1995, 1996 and 1997 [107.3 km/h (66.66 mi/h), 107.0 km/h (66.49 mi/h) and 108.8 km/h (67.59 mi/h)]. Since the numbers of data sites in Iowa were 1 and 2 in 1991 and 1992 respectively, they may not reflect the overall status of the whole state. If the data from 1991 and 1992 are removed from Figure 20, it is obvious that from 1994 to 2000, the mean speed of all vehicles in Iowa kept increasing every year.

In Group 2, although the two states showed increases in mean speed for all vehicles, they were not significant ($\alpha = 5\%$). Illinois always kept increasing, except for a negligible drop of 0.2%, from 100.9 km/h (62.68 mi/h) in 1993 to 100.6 km/h (62.55 mi/h) in 1994.

In Group 3, the Mean Speed for All Vehicles in Idaho increased significantly after the first 16.1 km/h (10 mi/h) speed limit increase for all vehicles, from 104.59/104.59 km/h (65/65 mi/h) to 120.68/120.68 km/h (75/75 mi/h), in 1996. When the second adjustment happened, which was from 120.68/120.68 km/h (75/75 mi/h) to 120.68/104.59 km/h (75/65 mi/h), the Mean Speed dropped, but not significantly.

In Group 4, the increase from the Before period to the After period was not significant. And it is clear that after the raise of speed limits from 104.59/88.50 km/h (65/55 mi/h) to 104.59/104.59 km/h (65/65 mi/h) in 1994, the mean speed increased by 2.4% from 107.4 km/h (66.76 mi/h) in 1993 to 109.9 km/h (68.33 mi/h) in 1995, which is also the peak value in the 1990's, even higher significantly than the 105.3 km/h (65.42 mi/h) in 2001.

5.3.2 Variable 2: Speed Variance for All Vehicles

Figure 21 shows the plotted Speed Variance of all the states, and the analyses results are presented in Table 44 and Table 45.

Figure 21 Speed Variance for all vehicles in all states

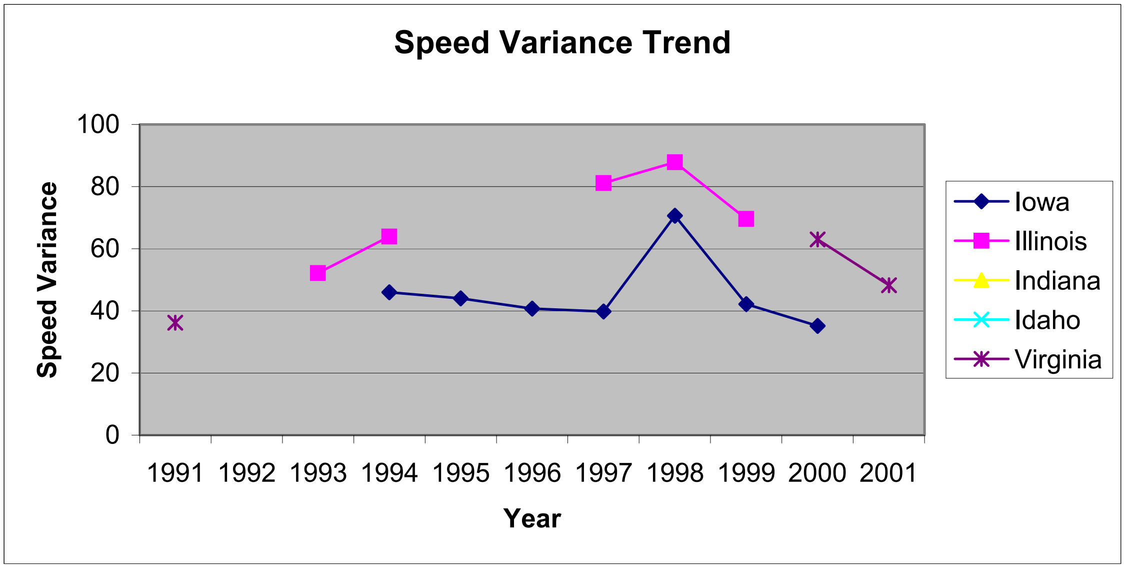

Table 44 ANOVA results of Speed Variance

Group	**State**	**Year-pair**		**Before-After**
		ANOVA(F/P)	**Post-Hoc**	**ANOVA(F/P)**
Group 1 (UNI-UNI)	IA	2.385/.019*	#	.024/.878(+)
Group 2 (DSL-DSL)	IL	2.291/.108	-	1.415/.250(+)
	IN	N/A	N/A	N/A
Group 3 (UNI-DSL)	ID	N/A	N/A	N/A
Group 4 (DSL-UNI)	VA	2.378/.121	-	2.587/.142(+)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,

Table 45 Post-Hoc results of Speed Variance

State	Variable	Levene' Sig.	Post-Hoc Test	Results	Note
IA	Speed Variance	.000	Dunnett	No significant difference between pair of years	1995<1998, 1996<1998, 1997<1998, 1999<1998, 2000<1998, by Tukey

As shown in Table 44, in Group 1, Iowa showed an insignificant difference on Speed Variance from the Before period to the After period. But due to an extremely high value (70.59) in 1998, it makes this year significantly greater than most of other years, which is shown in Table 45.

In Group 2, Indiana did not show any significant difference between the Before period and the After period, and the yearly variances did not show any significant fluctuations either.

In Group 4, no significant differences were found in Virginia, either in the Before-After or yearly comparison.

5.3.3 Variable 3: 85th Percentile Speed for All Vehicles

Figure 22 shows the plotted 85th Percentile Speed of all the states, and the analyses results are presented in Table 46 and Table 47.

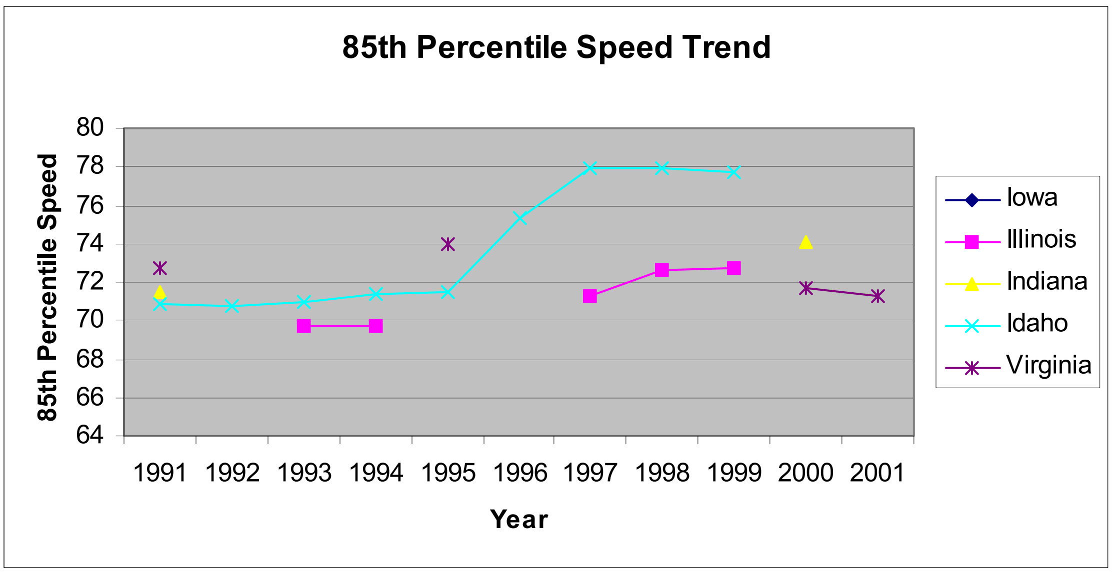

Figure 22 85th Percentile Speed for all vehicles in all states

Table 46 ANOVA results of 85th Percentile Speed

Group	State	Year-pair		Before-After
		ANOVA(F/P)	Post-Hoc	ANOVA(F/P)
Group 1 (UNI-UNI)	IA	N/A	N/A	N/A
Group 2 (DSL-DSL)	IL	.503/.734	-	2.033/.171(+)
	IN	N/A	N/A	1.124/.338(+)
Group 3 (UNI-DSL)	ID	126.401/.000*	#	577.003/.000* (+) .338/.563(-)
Group 4 (DSL-UNI)	VA	2.600/.081	-	.091/.768(-)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Table 47 Post-Hoc results of 85^{th} Percentile Speed

State	Variable	Levene' Sig.	Post-Hoc Test	Results	Note
ID	85th percentile Speed	.000	Dunnett's	1991<1996, 1991<1997, 1991<1998, 1991<1999, 1992<1996, 1992<1997, 1992<1998, 1992<1999, 1993<1996, 1993<1997, 1993<1998, 1993<1999, 1994<1996, 1994<1997, 1994<1998, 1994<1999, 1995<1996, 1995<1997, 1995<1998, 1995<1999, 1996<1997, 1996<1998, 1996<1999	

As shown in Table 46, in Group 2, both Indiana and Illinois only showed insignificant increases.

In Group 3, the 85% Speed for All Vehicles in Idaho increased significantly from [105.0 km/h (65.26 mi/h)] to [114.1 km/h (70.92 mi/h)] after the first 1.61 km/h (10 mi/h) speed limit increase for all vehicles in 1996, which was from 104.59/104.59 km/h (65/65 mi/h) to 120.68/120.68 km/h (75/75 mi/h). When the second adjustment occurred, from 120.68/120.68 km/h (75/75 mi/h) to 120.68/104.59 km/h (75/65 mi/h), the 85^{th} Percentile Speed dropped insignificantly from [114.1 km/h (70.92 mi/h)] to [113.9 km/h (70.81 mi/h)].

In Group 4, there were no significant differences found in 85^{th} Percentile Speed in Virginia

5.3.4 Variable 4: Median Speed for All Vehicles

Figure 23 shows the plotted Median Speed of all the states, and the analysis results are presented in Table 48 and Table 49.

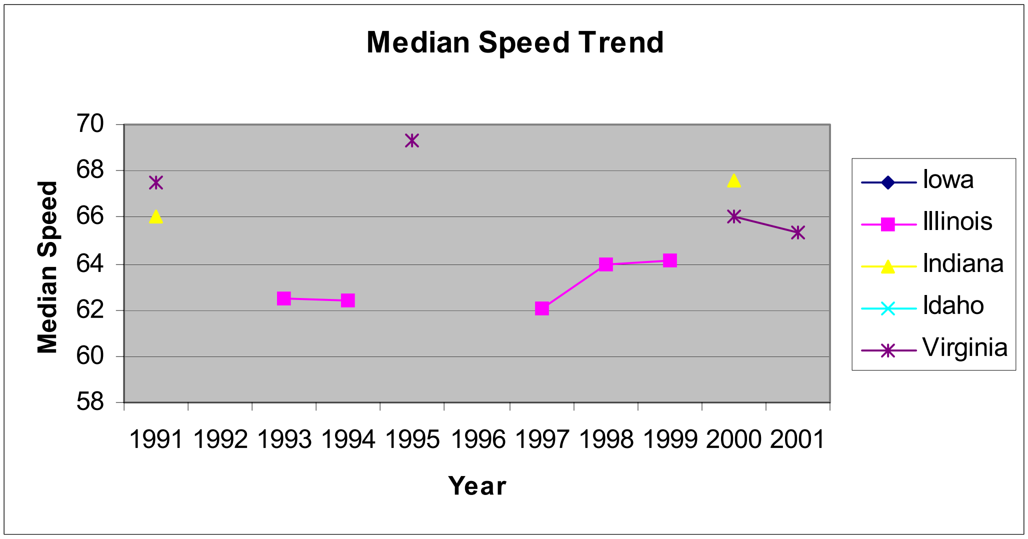

Figure 23 Median Speed for all vehicles in all states

Table 48 ANOVA results of Median Speed

Group	State	Year-pair		Before-After
		ANOVA(F/P)	Post-Hoc	ANOVA(F/P)
Group 1 (UNI-UNI)	IA	N/A	N/A	N/A
Group 2 (DSL-DSL)	IL	.295/.877	-	.401/.535(+)
	IN	N/A	N/A	.300/.608(+)
Group 3 (UNI-DSL)	ID	N/A	N/A	N/A
Group 4 (DSL-UNI)	VA	7.331/.002*	#	.173/.685(-)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Table 49 Post-Hoc results of Median Speed

State	Variable	Levene' Sig.	Post-Hoc Test	Results	Note
VA	Median Speed	.004	Dunnett	1991>2001, 1995>2000, 1995>2001	

In Group 2, this variable, Median Speed for All Vehicles, showed insignificant increases in both Illinois and Indiana, and no significant difference were found in yearly analysis.

In Group 4, the Median Speed for All Vehicles in 2000 and 2001 are significantly less than in 1991 and 1995. And no significant difference was found between the Before period [108.6 km/h (67.50 mi/h)] and the After period [107.9 km/h (67.05 mi/h)].

5.3.5 Variable 5: Noncompliance for All Vehicles

Figure 24 shows the plotted Noncompliance of all the states, and the analysis results are presented in Table 50 and Table 51.

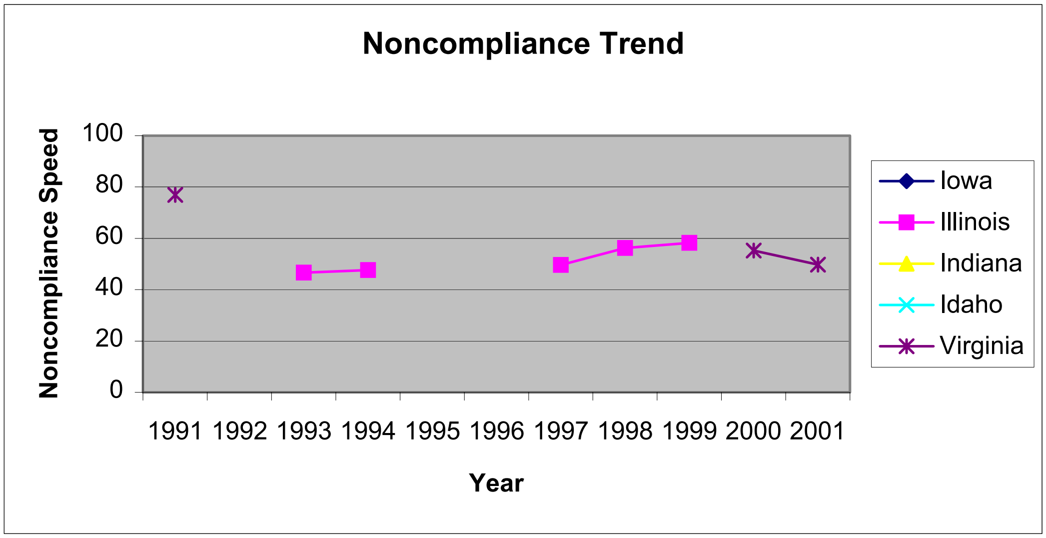

Figure 24 Speed Variance for all vehicles in all states

Table 50 ANOVA results of Speed Variance

Group	**State**	**Year-pair**		**Before-After**
		ANOVA(F/P)	**Post-Hoc**	**ANOVA(F/P)**
Group 1 (UNI-UNI)	IA	N/A	N/A	N/A
Group 2 (DSL-DSL)	IL	.317/.863	-	.921/.350(+)
	IN	N/A	N/A	N/A
Group 3 (UNI-DSL)	ID	N/A	N/A	N/A
Group 4 (DSL-UNI)	VA	11.944/.000*	#	12.897/.006(-)

Note: F/P – F-Ratio and P-Value of ANOVA test,
"*" after F/P – significant difference was found,
"#" in Post-Hoc column – Post-Hoc test was done,
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Table 51 Post-Hoc results of Speed Variance

State	Variable	Levene' Sig.	Post-Hoc Test	Results	Note
VA	Noncompliance	.017	Dunnett	1991>2000, 1991>2001	

In Group 2, the Noncompliance for All Vehicles kept rising in the 1990's, but always in an insignificant manner.

In Group 4, this variable obviously dropped from 76.94% in 1991 to 55.2% in 2000 and 49.81% in 2001, significantly at the 5% significance level.

5.3.6 Speed Analysis Results of Interstate Highways in Idaho

In Idaho, the sufficient number of sites available made it possible to conduct a detailed study on the variables mean speed and 85th percentile speed for the individual Interstate highways sites. Among these sites, three are in rural Interstate areas, and three other sites are in urban Interstate areas, with higher ADT's than those for the rural areas and a different speed limit policy. These urban sites were used as control sites.

Site information

Table 52 Descriptions of Idaho Interstate highways

Site	Speed Limit Change	Year
I-84 149	65/65 -- 75/75 -- 75/65	1996.5., 1998.7.
I-84 191	65/65 -- 75/75 -- 75/65	1996.5., 1998.7.
I-90 3559	65/65 -- 75/75 -- 75/65	1996.5., 1998.7.
I-84 51	55/55 -- 65/65	1996
I-90 616	65/65 -- 70/70	1996
I-90 862	65/65 -- 70/70	1996

Note: the first three sites are in rural areas, and the last three are in urban areas.

Figure 25 and Figure 26 show the plotted mean speed and 85th percentile speed of the six sites, and the analyses results are presented in Table 53.

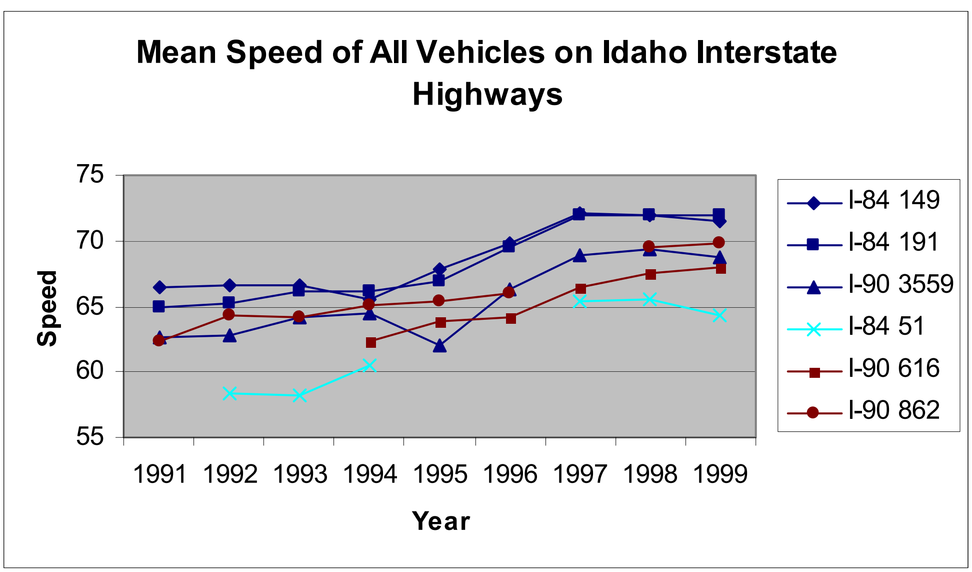

Figure 25 Mean Speed for all vehicles in Idaho

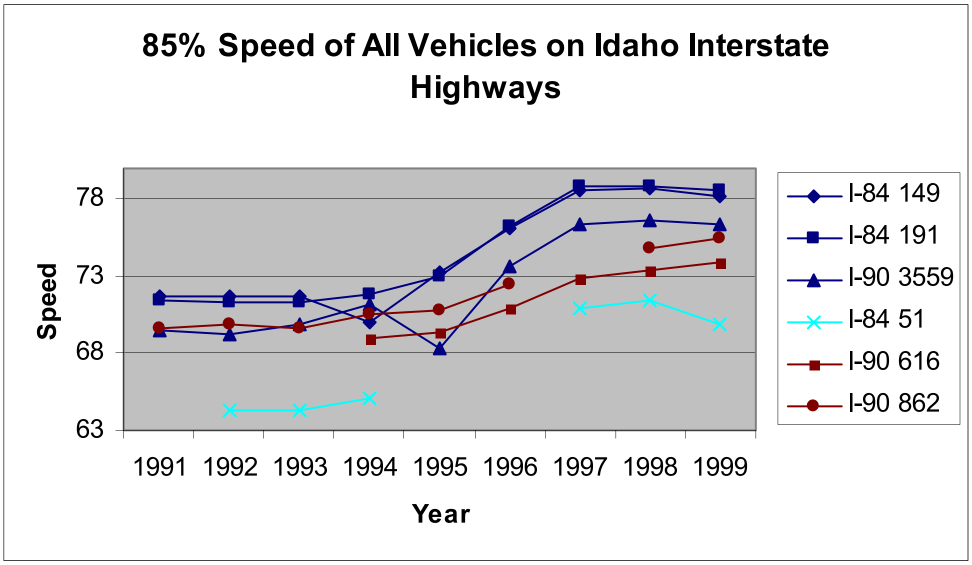

Figure 26 85th percentile Speed for all vehicles in Idaho

Table 53 ANOVA results of Mean Speed and 85th Percentile Speed in Idaho

Interstate	# of Data Points	Variable	Year-pair ANOVA(F/P)	Before-After ANOVA(F/P)
I-84 149	3 – 14	Mean Speed	85.228/.000*	371.633/.000(+)* 2.936/.099(-)
		85th Percentile Speed	95.263/.000*	352.835/.000(+)* 3.254/.084(-)
I-84 191	8 – 12	Mean Speed	148.136/.000*	482.603/.000(+)* .142/.710(-)
		85th Percentile Speed	148.948/.000*	630.376/.000(+)* 1.454/.241(-)
I-90 3559	8 – 12	Mean Speed	25.441/.000*	112.575/.000(+)* .007/.935(-)
		85th Percentile Speed	53.643/.000*	251.513/.000(+)* .006/.937(-)
I-84 51	6 – 12	Mean Speed	125.235/.000*	384.242/.000(+)*
		85th Percentile Speed	371.532/.000*	966.323/.000(+)*
I-90 616	3 – 12	Mean Speed	23.376/.000*	72.219/.000(+)*
		85th Percentile Speed	51.021/.000*	300.074/.000(+)*
I-90 862	6 – 12	Mean Speed	32.771/.000*	127.500/.000(+)*
		85th Percentile Speed	69.653/.000*	412.827/.000(+)*

Note:

I-84 149 – Mile Post 14.9 on Interstate 84
I-84 191 – Mile Post 19.1 on Interstate 84
I-90 3559 – Mile Post 35.59 on Interstate 90
I-84 51 – Mile Post 51 on Interstate 84
I-90 616 – Mile Post 61.1 on Interstate 90
I-90 862 – Mile Post 86.2 on Interstate 90
F/P – F-Ratio and P-Value of ANOVA test
"*" after F/P – significant difference was found

Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cells

From the time-series plots as shown in Figures 25 and 26, and comparison results shown in Table 53, it is obvious that:

- For those three rural sites, (I-84 149, I-84 191 and I-90 3559), significant increases on mean speed and 85th percentile speed were found after the first speed limit raise, and slight drops happened after the second speed limit change from 120.68/120.68 km/h (75/75 mi/h) to 120.68/104.59 km/h (75/65 mi/h) in 1998.
- The sudden drop on both mean speed and 85th percentile speed at site I-90 3559 in the year 1995 may be the result of some other factors, for example constructions
- For the three urban Interstate sites, the two variables, mean speed and 85th percentile speed, always kept increasing, but the significant increase was found only between the Before and After periods. This can be safely accounted for as an impact of the speed limits' changes.

5.4 Summary of Results and Discussions

The results of speed data analysis for all four groups are summarized in Table 54.

Table 54 Summary of speed data analysis results for all four groups

Group	State	Variable	Before-After Analysis Result	
			Difference	Significant
1	IA	Mean Speed	+	Y
		Speed Variance	+	N
		85th Percentile Speed		
		Median Speed		
		Noncompliance		
2	IL	Mean Speed	+	N
		Speed Variance	+	N
		85th Percentile Speed	+	N
		Median Speed	+	N
		Noncompliance	+	N
	IN	Mean Speed	+	N
		Speed Variance		
		85th Percentile Speed	+	N
		Median Speed	+	N
		Noncompliance		
3	ID	Mean Speed	+, -	Y, N
		Speed Variance		
		85th Percentile Speed	+, -	Y, N
		Median Speed		
		Noncompliance		
4	VA	Mean Speed	+	N
		Speed Variance	+	N
		85th Percentile Speed	-	N
		Median Speed	-	N
		Noncompliance	-	N

Note: "+" – Variable increased from the Before to the After period
"-" – Variable decreased from the Before to the After period
"N" – The difference is NOT significant ($\alpha = 5\%$)
"Y" – The difference is significant ($\alpha = 5\%$)
Since the speed limits were changed twice in Idaho, two sets of results are shown in the corresponding cell.

Based on the analysis results, some conclusions can be drawn, as follows:

- The variable mean speed, in Groups 1 and 2, the control groups, almost always kept increasing during the 1990's (except a 0.2% drop of Illinois in 1994), although there were not any changes in speed limits. For Idaho in Group 3 and Virginia in Group 4, during the years where no changes in speed limits occurred, the mean speed of all vehicles also kept increasing. This indicates that the mean speed has an increasing trend regardless of the speed limit changes.
- In most cases the mean speed, 85th percentile speed and median speed showed similar increasing trends. However in Illinois, the mean speed experienced a slight 0.2% drop from 100.9 km/h (62.68 mi/h) in 1993 to 100.6 km/h (62.55 mi/h) in 1994, although, this drop was not significant.
- In Idaho, the state in which the speed limits were altered two times (104.59/104.59 km/h (65/65 mi/h) to 120.68/120.68 km/h (75/75 mi/h) in 1996 and 120.68/120.68 km/h (75/75 mi/h) to 120.68/104.59 km/h (75/65 mi/h) in 1998), the mean speed and 85th percentile speed showed responsive changes, most significantly. This indicates that the increasing or decreasing of speed limits has expected effects on the speed distribution characteristics on the rural Interstate highways.
- In Iowa, the mean speed of all vehicles kept increasing from 1994 to 2000. Meanwhile, the variance of all vehicles continued to decrease, which indicates that more vehicles tend to drive at a higher speed on the rural Interstate highways.
- In Illinois, where no speed limit changes were implemented, the noncompliance kept increasing steadily. Considering the increasing mean speed, this could be credited to the demand for higher speed, which is consistent with the first conclusion.

In this Speed Analysis, there are some discussions that should be pointed out:

- In Virginia, the analysis sites were not able to be confined to the same ones throughout the study years, thus the results from this state do not show consistent trends with other states. This also indicates that in the same state, the speed characteristics vary with the specific locations.
- In Iowa, the numbers of data sites were only 1 and 2 in 1991 and 1992 respectively, which may not represent the actual situations in the whole state as accurately as in other years.

Chapter 6 Conclusions and Discussions

This chapter presents the final conclusions in this study, based on the Chapter 4 Crash Data Analysis and the Chapter 5 Speed Data Analysis,. And in the latter part of this chapter, some discussion is presented, and scope on future studies is considered.

6.1 Crash Analysis

- No obvious evidence was found to prove the relationship between the usage of DSL and uniform speed limits or the switch from these two types for speed limits and changing trends of crash rates.
- Based on the analyses of individual Interstates highways in Virginia, the diverse results suggest that the changes of Speed Limits did not play a dominant role in the trends of crash rates.
- Comparing the results with and without considering the range of ADT, the analysis results show significant discrepancies in some cases. This indicates that traffic volumes played an important role in the changing trends of crashes. Two experiments were carried out in Arizona and Virginia to explore the relationship between ADT's and crashes as shown in Appendix 1, but no clear patterns were found.

6.2 Speed Analysis

- The mean speed, 85^{th} percentile and median speed show a natural increasing trend. Meanwhile, the percentage of vehicles exceeding the speed limits kept increasing slightly as well. This indicates there has always been a need for higher speed on rural Interstate highways.
- The increasing or decreasing of speed limits had expected influences on the speed characteristics. Those influences were significant in some cases, for example with the raise of Speed Limits from 104.59/104.59 km/h (65/65 mi/h) to 120.68/120.68 km/h (75/75 mi/h) in Idaho, while in some other cases, the influences were not significant, for example, when Speed Limits were changed

from 120.68/120.68 km/h (75/75 mi/h) to 120.68/104.59 km/h (75/65 mi/h) in Idaho.

6.3 Discussions and Scope

- In this study, the analyses on crash rates indicate that the relationship between traffic volumes and crash counts was unclear, which possibly hinders the exploration of the impacts of speed limits on crash rates. In future studies, some other methodologies could be taken into consideration to make a non-linear model, other than using the traditional calculating crash rates.
- In speed analysis, the numbers of sites in several states, for example Virginia, Indiana and Illinois, are not sufficient to make the analysis result of these states as confident as in other states. For more discussions on difficulties in data collections, please refer to Appendix 2: Problems Encountered in the Data Collection

Appendix 1: Examination of the Effects of ADT on Total Crash Rates

In Chapter 4 Crash Analysis, the removal of extreme high and low ADT's was shown to have significant impacts on crashes. However, the relationship between ADT and crashes is still not clear. Intuitively, some may think that a high ADT tends to result in more interactions between vehicles so that more crashes would occur, but some others may think that in the case of heavy traffic, the drivers tend to pay more attention to the traffic conditions, which would possibly reduce the occurrences of crashes. To examine this impact, the following two experiments were conducted in this study.

A 1.1 Histograms of ADT vs. Total Crash Rate

The data employed in these histograms were the total crash rates and related ADT's from two states: Arizona and Virginia. The highest 5% and lowest 5% of ADT's were removed from the data set, regarded as extreme conditions. Histograms were drawn for the total crash rates by ADT ranges. For Arizona, one plot was made, considering that no speed limits occurred in this state. For Virginia, two histograms were made for the Before period and the After period respectively, in order to remove the potential impacts of the speed limit change which occurred in 1994. To be specific, the analysis years were from 1991 to 2000 in Arizona, from 1991 to 1993 in Virginia for the Before period, and from 1995 to 1999 in Virginia for the After period

The experiment results are shown in the sections A 1.1.1 and A 1.1.2.

A 1.1.1 Histograms of ADT vs. Total Crash Rate in Arizona

Table 55 shows the statistics of total crash rates in Arizona from 1991 to 2000. Figure 27 plots the total crash rates vs. ADT.

Table 55 Statistics of total crash rates in Arizona from 1991 to 2000

Arizona	
Mean	12606.9
Standard Error	225.8124
Median	8500
Standard Deviation	11295.13
Sample Variance	1.28E+08
Kurtosis	5.92656
Skewness	2.486366
Range	59139
Minimum	3697.5
Maximum	62836.5
Sum	31542464
Count	2502

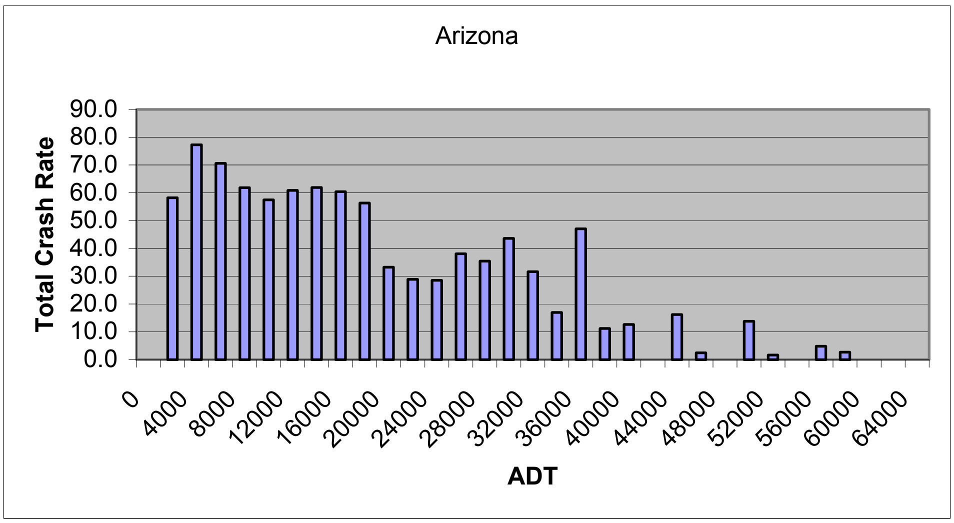

Figure 27 Total Crash Rate vs. ADT in Arizona

A 1.1.2 Histograms of ADT vs. Total Crash Rate in Virginia

Tables 56 and 57 show the statistics of total crash rates in Virginia from 1991 to 1993 (the Before period) and from 1995 to 1999 (the After period) respectively. Figures 28 and 29 plot the total crash rates vs. ADT for the two periods respectively.

Table 56 Statistics of total crash rates in Virginia (the Before Period)

Virginia (Before)	
Mean	13386.29
Standard Error	201.5393
Median	13000
Standard Deviation	4977.655
Sample Variance	24777047
Kurtosis	4.509529
Skewness	1.751516
Range	28595.79
Minimum	5000
Maximum	33595.79
Sum	8165636
Count	610

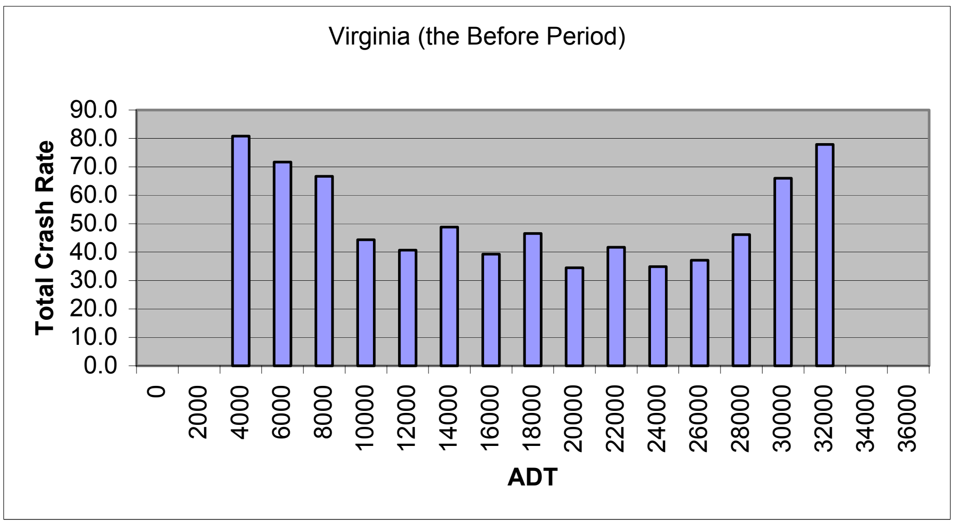

Figure 28 Total Crash Rate vs. ADT in Virginia (the Before Period)

Table 57 Statistics of total crash rates in Virginia (the After Period)

Virginia (After)	
Mean	15649.06
Standard Error	140.7245
Median	15794.61
Standard Deviation	4648.17
Sample Variance	21605485
Kurtosis	2.145077
Skewness	0.674831
Range	30298.92
Minimum	4701.084
Maximum	35000
Sum	17073126
Count	1091

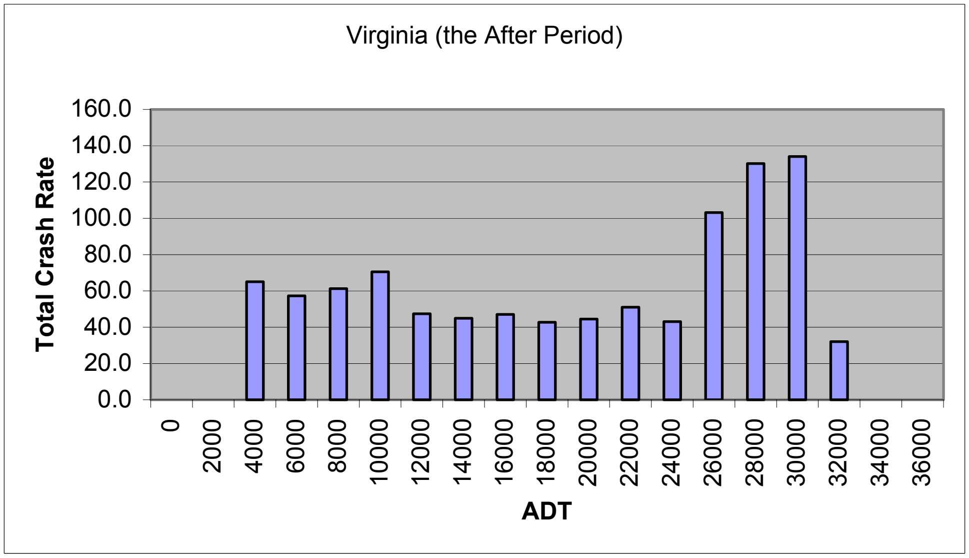

Figure 29 Total Crash Rate vs. ADT in Virginia (the After Period)

In Arizona, as shown in Figure 27, the general trend indicates when the ADT increased, the total crash rates decreased, but this pattern was not clear. In Virginia, as shown in Figures 28 and 29, both the Before and the After period did not suggest any regular pattern between the ADT's and the total crash rates.

A 1.2 Two-way ANOVA Analysis

Two-way ANOVA analyses were conducted in both Arizona and Virginia to examine the effects of both ADT and speed limits on total crash rate.

In these ANOVA analyses, two independent variables were ADT and Speed Limits, and the dependent variable was Total Crash Rate. Speed Limits had two levels: Before and After, and ADT had 3 levels in Virginia and 5 levels in Arizona, which was due to the different ADT ranges in the two states. The definitions for the levels of these two variables are shown in Table 58.

Table 58 Level definitions for two-way ANOVA

Variable	State	Level	Definition	Note
Speed Limits	Virginia	1	1991 - 1993	Year
		2	1995 - 1999	Year
	Arizona	1	1991 - 1995	Year
		2	1996 - 1999	Year
ADT	Virginia	1	0 - 14999	ADT Value
		2	15000 - 27499	ADT Value
		3	27500 - 39999	ADT Value
	Arizona	1	0 - 14999	ADT Value
		2	15000 - 27499	ADT Value
		3	27500 - 39999	ADT Value
		4	40000 - 52499	ADT Value
		5	52500 - 65000	ADT Value

The two-way ANOVA results are shown in Tables 59 and 60.

Table 59 Two-way ANOVA results for Arizona

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	692674.348[a]	9	76963.816	22.487	.000
Intercept	365693.055	1	365693.055	106.848	.000
BORA	7570.345	1	7570.345	2.212	.137
ADT	480476.984	4	120119.246	35.096	.000
BORA * ADT	36564.203	4	9141.051	2.671	.031
Error	8529027.298	2492	3422.563		
Total	18507548.5	2502			
Corrected Total	9221701.646	2501			

Note: BORA – The variable Speed Limit
ADT – The variable ADT

As shown in Table 59, no significant difference was found from the Before period to the After period in Arizona (P-value = 0.137, α = 5%). The variable ADT was found to have significant influence on total crash rates (P-value = 0.000, α = 5%). Meanwhile, the interaction of these two variables resulted in significant differences on total crash rates in Arizona (P-value = 0.031, α = 5%).

Table 60 Two-way ANOVA results for Virginia

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	59074.774[a]	5	11814.955	9.438	.000
Intercept	1034578.071	1	1034578.071	826.446	.000
BORA	2891.319	1	2891.319	2.310	.129
ADT	45023.284	2	22511.642	17.983	.000
BORA * ADT	746.468	2	373.234	.298	.742
Error	2121868.836	1695	1251.840		
Total	6480839.204	1701			
Corrected Total	2180943.611	1700			

Note: BORA – The variable Speed Limit
ADT – The variable ADT

As shown in Table 60, no significant difference was found from the Before period to the After period in Virginia (P-value = 0.129, α = 5%). The variable ADT was found to have significant influence on total crash rates (P-value = 0.000, α = 5%). Meanwhile, the interaction of these two variables did not result in any significant differences on total crash rates in Virginia (P-value = 0.742, α = 5%).

A 1.3 Conclusions

Based on the findings in Sections A 1.1 and A 1.2, the following conclusions can be drawn:

- The impacts of ADT on total crash rates were shown to be significant in both Arizona and Virginia. However, In Arizona, the higher ADT tended to reduce the total crash rates, while no obvious relationship was found in Virginia.
- The interaction of ADT and speed limits did not show consistent impacts on total crash rates between the two states.

Appendix 2: Problems Encountered in the Data Collection

During the course of data collection, which is the most laborious and time-consuming process in this study, several problems were encountered. These problems were mainly in the following areas: problems on data requests and thus the time delays caused, and data incompatibilities among different states. The following sections discuss each of the aspects.

A 2.1 Problems in Data Requests

Beginning in June in 2001, data requests were sent out to the relevant data management departments of each selected state. Before making the requests, the data needed in this study were discussed thoroughly, and the request letters were drafted and revised several times to make them as accurate as possible

However, some of the data management departments were confused on certain points in the letters, and several questions about them were raised. Their questions were discussed carefully, and another round of data requests were sent out. Some questions were raised again. This situation continued for months, varying in different states, and caused some extra time delays.

In some states, the traffic data were managed by several coordinating agencies, so our request had to be processed throughout the whole system to obtain the data requested. This also resulted in more time delays.

A 2.2 Problems in Data Incompatibility

Another obstacle in this study was the data incompatibility. This came from the fact that the states have been employing different data recording systems. For crash data, Arizona provided us with all the incident data retrieved from a huge Oracle database, with some index files. For clarification of the exact meaning of table, indices and fields, we communicated with the data management departments back and forth, to make sure we could get the exact crash data out of the incident tables. In Iowa, the crash data were given in hardcopy by individual sites on several Interstate highways. For each site, one page of detailed descriptions was given.

For speed data, some states did not have a continuous record throughout the 1990's. For example, North Carolina could only provide speed summaries from 1991 to 1994, and California could only furnish daily traffic counts in 1999 and 2000. This made it not inpractical to do speed analysis in those states.

A 2.3 Suggestions for Future Researchers

In this section, several suggestions are given to future researchers who will use similar data collection methods.

- In this study, the objective was to investigate Interstate highway segments that were rural. During the process of filtering eligible sites, opinions from experienced persons should be taken. For example, in screening sites in Virginia, Mr. Lewis Woodson, who works for VTRC (Virginia Transportation Research Council) helped a lot, and based on his suggestions, all segments on Interstate 66 were removed out of our data set, because although quite a sections of this highway were designed as rural section, the high volumes turned them into more than rural sections in reality.
- The data requests should be as detailed and accurate as possible, and some specific examples help greatly. However, even with this care, some time should be budgeted for unexpected confusions.
- Due to the data incompatibility, some variables should not be expected for every state. For example, in terms of speed variables, only Mean Speed for All Vehicles could be guaranteed in every state, and availabilities of other variables depended on the specific state, especially for truck-related speed data. Quite a few states do not have data available regarding vehicle classifications.

Appendix 3: Data Filtering by ADT

In both the Crash and Speed Analysis, the sites were filtered according to the ADT (Average Daily Traffic). The purpose of this was to remove the potential impacts of traffic volume on crashes and speed characteristics. In this Appendix 3, the method employed in ADT confinement is described.

To illustrate this method, a simple example is used, and the data are invented for clarity. For example, in state A, there are 50 sites whose crash data were provided from 1993 to 1996 as were their ADT data in each year. The data are shown in Table 61:

Table 61 Summary of Crashes and ADT's in state A

Site	Year	Crashes	ADT
1	1993	12	11000
1	1994	15	12000
1	1995	9	15000
1	1996	11	20000
2	1993	6	9800
2	1994	5	13000
2	1995	9	15000
2	1996	12	16000
,,, ,,,	,,, ,,,	,,, ,,,	,,, ,,,
49	1993	10	11000
49	1994	9	12000
49	1995	6	15000
49	1996	15	20000
50	1993	10	15000
50	1994	9	17000
50	1995	6	17800
50	1996	15	21000

Then, the minimum ADT and maximum ADT of each site from 1993 to 1996, are found. The results are shown in Table 62.

Table 62 Minimum ADT and Maximum ADT of each site

Site	Minimum ADT	Maximum ADT
1	11000	20000
2	9800	16000
,,, ,,,	,,, ,,,	,,, ,,,
49	11000	20000
50	15000	21000

In the next step, the statistics of Minimum ADT's and Maximum ADT's are calculated respectively. The results are shown in Table 63 and Table 64:

Table 63 Distribution of Min. ADT's

Minimum ADT	
Mean	12200.00
Standard Error	1254.71
Median	13000.00
Mode	12500.00
Standard Deviation	3548.84
Range	9000.00
Minimum	9000.00
Maximum	18000.00
Sum	610000.00
Count	50.00

Table 64 Distribution of Max. ADT's

Maximum ADT	
Mean	18100.00
Standard Error	1355.71
Median	18300.00
Mode	18250.00
Standard Deviation	3758.84
Range	7500.00
Minimum	15000.00
Maximum	22500.00
Sum	228800.00
Count	50.00

Based on the means, medians and modes of Minimum ADT's and Maximum ADT's shown in Table 63 and Table 64, the lower and upper limits of the final ADT range are selected. For example, in this case, the lower limit could be selected as 12500, and the upper limit could be 18200. In case that too few sites, for example, only 5 or 6, were left after the filtering, the ADT Range could be made looser to make sure enough sites could be left for future analysis. One advantage of this method is that when the final ADT range is applied to filter all sites, it can be made sure that sites selected finally are the same for each year.

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