

Article

Speed Characteristics in Relation to Speed Limit Increase and Its Influence on Driver's Speed Selection Behavior

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Abstract: Speed is a quality measurement for travel, since it is related to traffic, safety, time, and economics. The speed limit on selected freeways in Kansas changed from 70 mph to 75 mph in the summer of 2011. In this study, the driver's speed selection behavior was analyzed by considering average speed and 85th percentile speed in the before and after periods. Data from Automatic Traffic Recorders (ATRs) on the sections affected by speed limit increase and sections with no speed limit increase were analyzed. The *t*-test was applied to investigate if there was any significant difference in the speed of drivers on both treated and control sections. The Kolmogorov-Smirnov (K-S) test was also conducted to see if the distribution of speed data in the before period was different than after the period. The results showed that for the majority of the sections affected by speed limit change, there was a statistically significant difference in the 85th percentile speed of drivers during after period. Additionally, the K-S test results showed that the distribution of speed data in the before period was different than after the period for the majority of treated sections. The results indicated how drivers' behavior was influenced by the speed limit increase.

Keywords: speed limit; speed distribution; 85th percentile speed; freeway; driver's behavior; sustainable transportation system

1. Introduction

Speeding is a common habit for drivers. Exceeding the speed limit and driving too fast for conditions is one of the traffic violations that often happens on the roads. High speed causes safety problems for road users and increases air pollution and traffic noise. Speed limits are generally considered as the peak travel speeds under good weather conditions, uncongested traffic, and clear visibility. Appropriate speed limits are essential for ensuring safe highways and streets. In 2011, Kansas legislature passed the new maximum speed limit law on selected segments of freeways. Accordingly, more than 800 miles of freeways in Kansas saw a speed limit increase from 70 mph to 75 mph as the maximum speed limit on these sections. It was thought that drivers were already driving 5–10 miles above the posted speed limit and therefore it made sense to make it formal. Speed limit increase was expected to help the economic development of Kansas, via travel time savings. It was also pointed out that the higher speed limit would help make regulations match reality because many passengers drive faster in the open country anyway. On the other hand, opponents were saying that drivers would not change their behavior and would drive 5–10 miles more than the new posted speed limit, where higher speed might negatively influence safety and may increase the number and severity of crashes [1].

In the past, several research studies have evaluated the effect of a driver's speed and its impact on traffic safety. The speed of a driver from one journey to another may not be the same and there could be circumstances that a driver is controlling a vehicle out of speed limit. For example, for one trip, the driver may need to reach his/her destination hastily or the driver may not have good enough concentration while driving and it would affect the speed of vehicle [2]. Speeding is the main problem in traffic safety and a driver's age and sex are good predictors of selected speeds, and young drivers drive faster than old drivers. Additionally, male drivers are faster than female drivers and speed increases with vehicle power-to-weight ratio and decreases with the vehicle age [3].

Speed limit changes may have a significant impact on free-flow speed. According to a Canadian study conducted by Islam et al. [4], when the posted speed limit was reduced from 50 to 40 km/h, it resulted in a 4.9 km/h actual speed reduction after 6 months from the speed limit change. Elvik [5] considered speed limit changes for multiple research studies and understood that a 10 km/h change in the speed limit value could cause 2.5 km/h change in the mean speed, which shows that speed limit change has influenced the actual driver's speed.

Silvano and Bang [6] considered the impact of speed limit changes on free-flow speeds in urban areas in Sweden. Standard deviation, 85th percentile speed, and confidence interval for mean free-flow speed were identified and a two-sample *t*-test was applied for the analysis to observe statistically significant changes in the mean free-flow speed after speed limit decrease. The results depicted that a decreased Posted Speed Limit (PSL) caused a small reduction in the mean free-flow speed and speed variance, which was statistically significant and led to a 10% reduction of severe injury accidents. Additionally, the PSL reduction had a larger effect on faster drivers and higher capacity highways.

Brown et al. [7] performed speed data analysis when the speed limit raised from 55 mph to 65 mph in Alabama. The speed study revealed that around half of the vehicles exceeded the PSL on the rural interstates after the speed limit increase. Najjar et al. [8] evaluated the 85th percentile speed according to the before and after posted speed limit increases in Kansas from 55 mph to 60 mph in March 1996. The 85th percentile speed in the before period was compared to the after period, where the two-tailed *t*-test was employed to investigate if a statistically significant difference in 85th percentile speed between before and after speed data could be seen at 95% confidence level. The results showed that there was a statistically significant difference between before and after speed limit increases. Shirazinejad and Dissanayake [9] analyzed the speed characteristics before and after the speed limit increases using a *t*-test. The results showed that there was a statistically significant increase in the 85th percentile speed of drivers after speed limit increases compared to the before period.

Binkowski et al. [10] evaluated speed characteristics when the speed limit increased from 65 mph to 70 mph for freeways in Michigan. According to the authors, there was an increase in both average and 85th percentile speeds for some of the test sites, but the statistical significance of the change in speed was not possible to be observed, because the sample size was so large.

In Iowa, the speed limit on most of the rural interstates changed from 65 mph to 70 mph in 2005. The speed data were available for 11 months before the speed limit change and 18 months after. To test the statistical significance of the 85th percentile speed, a generalized regression model was implemented to identify if speed limit change has been significant or not. It was known that on the rural interstates, the mean and 85th percentile speeds increased by about 2 mph and the increases were statistically significant [11]. Aronsson and Bang [12] also used linear regression models for predicting the mean speed on various road types according to their facility type, such as arterial and multilane highways in rural or urban roads. Further, statistical analysis approaches such as *t*-test is commonly used for speed analysis during the before-and-after comparisons based on the safety impacts of speed limit changes and it showed statistically significant difference after speed limit increase in Texas [13].

There are several ways of collecting speed data in each state in order to conduct speed data analysis. For example, Wang [14] utilized the Global Positioning System (GPS) data from vehicles to estimate operating speeds on low-speed urban roads in Georgia. So, collecting the speed data in each state is different and it depends on the most appropriate and available facilities.

Therefore, the goal of this study is to examine the effect of speed limit increase on actual speeds of vehicles and viewing the drivers' speeding behavior on rural and urban highways affected by speed limit increase. Additionally, there is some information about the crash statistics in the before period and after a period, which is shown in Figure 1.

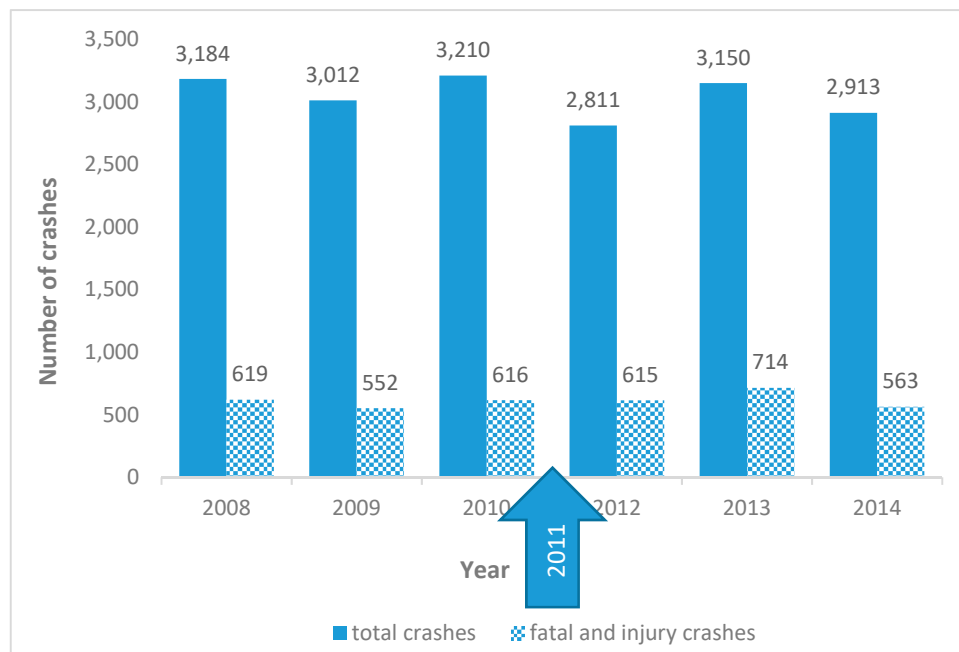


Figure 1. Crash distribution before and after speed limit change.

The Figure 1 represents how speed limit increase caused changes in the total number of crashes and fatal and injury crashes. However, the increase exists in the before period, too, and needed further crash data analysis for an accurate conclusion, in which some crash data analysis methods are recommended. In this study, the main focus is analyzing the speed characteristics to understand if the speed limit increase has significantly affected the drivers' speed selection behavior, because the higher operating speeds may eventually affect the traffic safety and sustainable transportation system.

2. Methodology

To check if there are any statistically significant differences in the before period compared to after period, the two-tailed *t*-test is applied. On the other hand, the Kolmogorov-Smirnov(K-S) test is also conducted to see if the speed data distribution during the before speed limit increase is different than after the period or not.

2.1. Data

There are Automatic Traffic Recorders (ATRs) in Kansas that record the number of vehicles passing per hour in different speed ranges automatically. In this study, comparison site selection was selected based on matching, as closely as possible, the geometric characteristics, volume, and speed characteristics of the experimental sites (sites studied by the highway agencies for speed limit revisions). Furthermore, the sections less than 0.5 miles were not selected according to Highway Safety Manual [15] recommendations, and geographic and urban or rural conditions were also important for identifying the sections. Accordingly, 27 sites were selected as control sites (sites with 70 mph speed limit) and 39 sites as treated sites (sites with 75 mph speed limit). According to the speed data, there are some available ATRs located on control sites and treated sites to collect the speed data. The location of each ATR is plotted in Figure 1. The location of each ATR and the number of vehicles in different speed bins starting from 40 mph to 95 mph in divisions of 5 mph such as 40 mph-45 mph, 45mph

-50mph, and so forth are obtained from Kansas Department of Transportation (KDOT). To analyze the speed characteristics, it was decided to compute and compare both average speed and 85th percentile speed but the 85th percentile speed is more common among traffic engineers as the main factor for evaluating the operating speeds [6]. So, the 85th percentile speed increase suggests that most drivers were affected by speed limit change and they continued driving at a higher speed more than they felt comfortable than the previous speed limit. The locations of ATRs are shown in Figure 2.

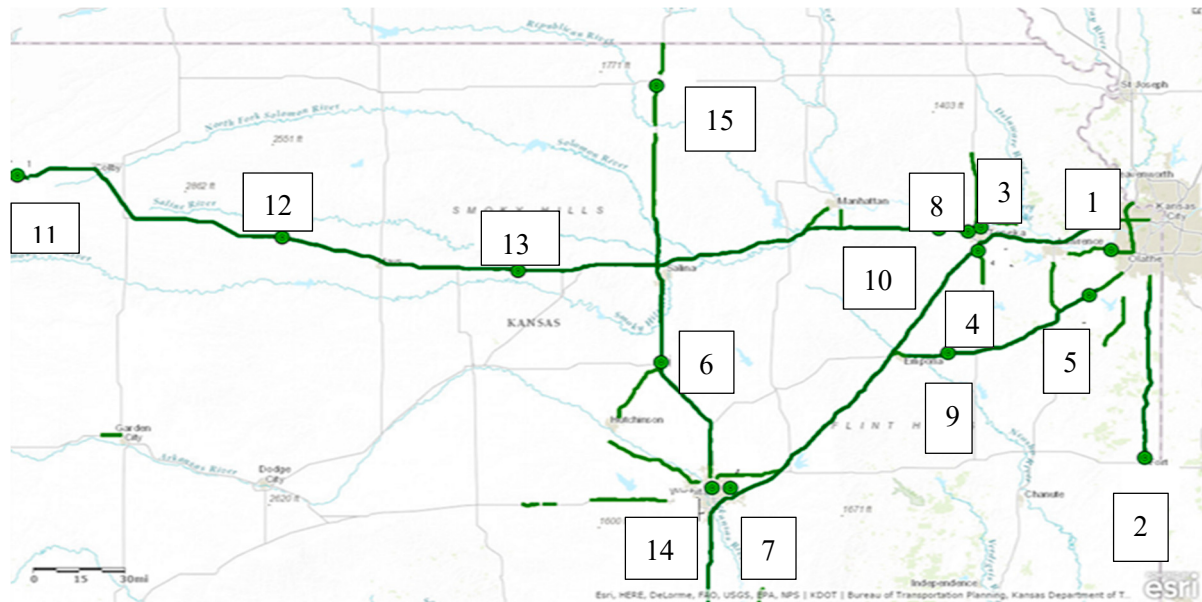


Figure 2. Location of selected Automatic Traffic Recorders on freeway segments.

Each ATR provided the number of vehicles passing the location and the speed distribution in one-hour time intervals for one year before speed limit change (2010) and one year after the change (2012). However, the data for the year 2010 was not available for all months. So, it was decided to compare each ATR data based on the available months in the year 2010 with the same corresponding months in the year 2012. The identification label of each ATR along with the availability of data during before and after speed limit increase are tabulated in Table 1.

Table 1. ATR characteristics with available data for before and after speed limit change.

ATR Number(Rural/Urban)	Site Characteristic		Data Availability	
	Control Site	Treated Site	The Year 2010	The Year 2012
1-EFPRX3(rural)	✓		March, September, December	January to December
2-F10VD5(rural)		✓	June	January to December
3-CXJUQ3(rural)		✓	June, September, November, and December	January to December
4-CXSRG1(urban)	✓		September, November, and December	January to December
5-E7PK42(urban)		✓	December	January to December
6-94J8N1(rural)		✓	September and December	January to December
7-A0OOS8(rural)	✓		March, June, September, and December	January to December
8-CB1U73(rural)		✓	September and December	January to December
9-CO1AY7 (rural)		✓	March, June, and September	January to December
10-CTGTW8 (urban)		✓	September, November, and December	January to December
11-0DT453 (urban)		✓	September and December	January to December
12-4LGSU7 (rural)		✓	September and December	January to December
13-7FGNB7 (rural)		✓	September and December	January to December
14-9Q9OK1 (rural)		✓	March to June, September and December	January to December
15-91TFY5 (urban)	✓		September and December	January to December

2.2. Two-Tailed *t*-Test

The two-tailed *t*-test is applied in this study for comparing 85th percentile speed and average speed in the before period and after periods. The two-tailed *t*-test is employed to identify whether a statistically significant difference exists in speeds between the before period and after the period at a 95% confidence level. To apply the *t*-test, some assumptions need to be met, which are listed as follows [16]:

1. The observations from two groups (before period and after the period) are normally distributed.
2. The variances of two groups are checked to see whether they are equal or not.
3. The observations in each group are independent of each other.

The critical *t*-value is selected from the standard tables of *t*-values based on the significance level (95%) and the degree of freedom. The comparison of calculated *t*-value with critical *t*-value determines whether the null hypothesis can be rejected at 95% confidence level or not. The *t*-test procedure of STATA software [17] was also utilized in this research to compute the *t*-values.

The *p*-value is the primary factor for the *t*-test on validating the null hypothesis; which is interpreted as when the *p*-value is less than 5%, the null hypothesis is rejected and the alternative hypothesis would be accepted at 95% confidence level. On the contrary, when the *p*-value is greater than 5%, the alternative hypothesis is rejected and the null hypothesis would be accepted at a 95% confidence level [18].

2.3. Kolmogorov-Smirnov (K-S) Test

The Kolmogorov-Smirnov (K-S) test is also applied in this study since the sample size is large. The K-S test is based on the Empirical Distribution Function (EDF). This test is defined for comparing two different data distributions of sizes *m* and *n*, and the hypothesis test for checking two different distributions is as follows [19]:

H_0 : The distribution for one set of data is the same as the second set of data

H_a : The distribution for one set of data is different than the second set of data and the Kolmogorov-Smirnov test statistic is defined as:

$$D_{n,m} = \sup_x |F_{1,n}(x) - F_{2,m}(x)| \quad (1)$$

where,

$D_{n,m}$ = the test statistic for the difference between two distributions

$F_{1,n}(x)$ & $F_{2,m}(x)$ = empirical distribution functions for the first and second samples

Sup = supremum function

n, *m* = sizes of first and second sample, respectively.

The null hypothesis that the distribution of two sets of data is the same was verified through applying R software package [20], which is very common to apply for K-S test and check if the probability (*p*-value) is greater than 0.05 at 95% confidence level, otherwise, there is no evidence that the two sets of data come from the same distribution.

3. Results

3.1. Two-Tailed *t*-Test Results

The frequency distribution curves of all available ATRs were drawn and the test of normality for each ATR was conducted separately. The ATRs 6 and 11 were not normally distributed and they were removed. So, the speed analysis was carried out for the remaining ATR locations, which were normally

distributed for both before and after periods. Table 2 presents the 85th percentile speed and two-tailed *t*-test results for 13 ATRs that include both treated sites and control sites. The sample sizes in the before period are different than the after period and the F-test results also showed that the variances of two groups of data in the before period is not equal to the after period. The final results are summarized in Table 2 and the statistical significance results are also identified at a 95% percent confidence level according to the STATA statistical software package.

Table 2. Results of the two-tailed *t*-test for 13 ATRs during before and after speed limit change (85th percentile speed).

ATR#	Treated/ Control Site	Sample Size		Before	After	<i>t</i> -Value	Two-Tailed <i>t</i> -Test	
		Before the Period	After the Period	85 th Percentile Speed (mph)	85 th Percentile Speed (mph)		<i>p</i> -Value	Statistically Significant Difference (Yes/No)
1	Control	1,401,188	3,031,690	77.65	77.83	−32.14	0.00	Yes
2	Treated	77,496	397,177	76.82	79.65	−128.00	0.00	Yes
3	Treated	1,409,912	5,226,224	74.42	74.28	26.92	0.00	Yes
4	Control	315,487	1,272,566	75.50	75.67	−14.16	0.00	Yes
5	Treated	282,760	601,588	77.32	79.72	−184.00	0.00	Yes
6	Control	816,304	2,646,833	72.50	72.37	21.00	0.00	Yes
7	Treated	868,023	1,127,571	78.40	80.89	−276.00	0.00	Yes
8	Treated	427,132	1,216,287	77.72	80.02	−232.00	0.00	Yes
9	Treated	676,551	2,326,592	69.11	69.33	−27.50	0.00	Yes
10	Treated	231,817	375,564	77.03	81.29	−266.00	0.00	Yes
11	Treated	273,166	310,952	77.37	81.23	−241.00	0.00	Yes
12	Treated	4,411,134	8,814,389	68.94	69.21	−100.00	0.00	Yes
13	Control	144,368	222,132	76.13	75.72	22.77	0.00	Yes

According to the two-tailed *t*-test results presented in Table 2, the 85th percentile speed increased on the majority of the sections after the speed limit increase. Additionally, the results show that the 85th percentile speed increase in both treated and non-treated sections is statistically different from each other in the before period compared to the after period.

The statistically significant difference between before and after the period for all of the sections is due to the large sample size in this research, that any change in 85th percentile speed would be significant as recognized by previous research as well [10]. The *t*-test results for the average speed are also presented in Table 3.

Table 3. Results of the two-tailed *t*-test for 13 ATRs during before and after speed limit change(Average speed).

ATR#	Treated/ Control Site	Sample Size		Before	After	Two-Tailed <i>t</i> -Test	
		Before the Period	After the Period	Average Speed (mph)	Average Speed (mph)	<i>p</i> -Value	Statistically Significant Difference (Yes/No)
1	Control	1,401,188	3,031,690	71.95	72.00	0.00	Yes
2	Treated	77,496	397,177	71.09	73.56	0.00	Yes
3	Treated	1,409,912	5,226,224	69.04	68.68	0.00	Yes
4	Control	315,487	1,272,566	70.08	69.71	0.00	Yes
5	Treated	282,760	601,588	71.74	73.66	0.00	Yes
6	Control	816,304	2,646,833	67.34	67.15	0.00	Yes
7	Treated	868,023	1,127,571	73.15	73.46	0.00	Yes
8	Treated	427,132	1,216,287	72.04	74.07	0.00	Yes
9	Treated	676,551	2,326,592	63.21	63.53	0.00	Yes
10	Treated	231,817	375,564	71.26	74.19	0.00	Yes
11	Treated	273,166	310,952	71.50	74.34	0.00	Yes
12	Treated	4,411,134	8,814,389	64.03	64.31	0.00	Yes
13	Control	144,368	222,132	70.76	70.38	0.00	Yes

According to Table 3, there is also an increase in the average speed of vehicles in the after period compared to the before period for the treated sections and not much change in the control sections. However, ATR#3 shows a decrease in average speed in the after period compared to the before period and this is because of the large sample size in the after period versus the before period. Since the sample size is too large, the K-S test is recommended to be conducted in this study in order to obtain better results [10]. In addition, since the two-tailed *t*-test results may not be very satisfying and may not help to identify if the speed limit increase has had any more prominent effect on treated sites than non-treated sites, the K-S test, which is commonly used to compare two different distributions with large sample size is employed and the results are shown in Section 3.2.

3.2. K-S Test Results

The K-S test is applied to check if two sets of speed data are differently distributed or not. For this purpose, as an example, the first two ATRs distribution curves are presented in Figure 3 to show how speed data is differently distributed.

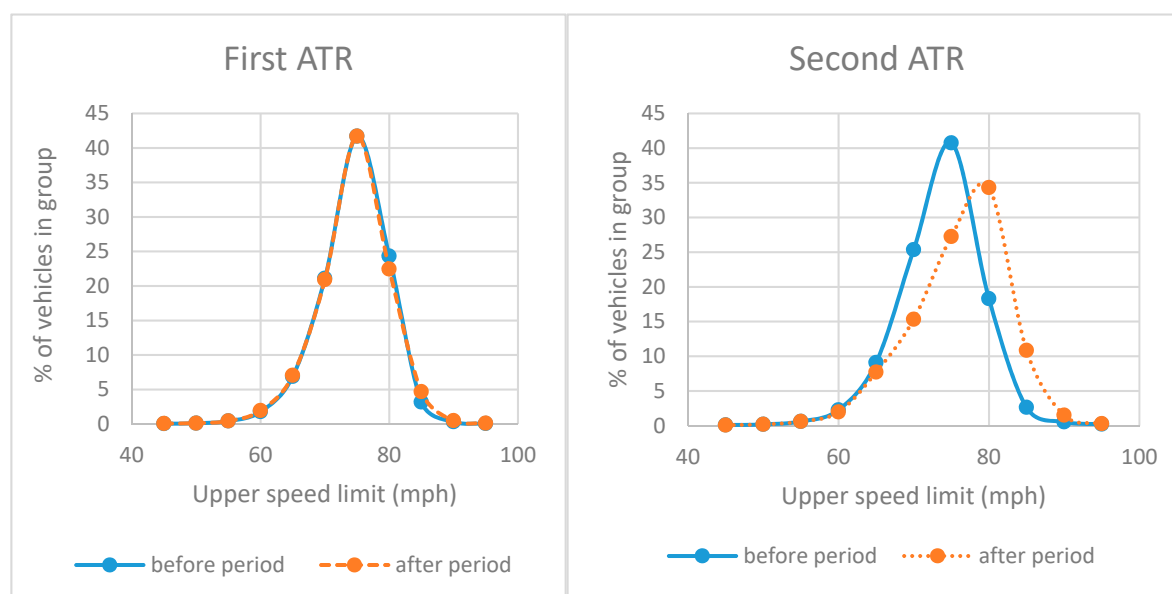


Figure 3. Sample K-S test distributions for the first two ATRs during before and after periods.

According to Figure 3, it is obvious that the speed distribution during the before period for the first ATR is similar to the after period and there is no difference between before and after speed limit increase. However, the speed distribution during the before period for the second ATR is differently distributed compared to the after period and this means that the drivers' speed in the before speed limit increase is not equal to the drivers' speed during the after speed limit increase. To evaluate the statistically significant difference of the remaining ATRs in the before period compared to the after period, the K-S test application of R software package is used to obtain the test statistic (D), and critical D along with the probability value (p -value) for identifying the statistically significant difference between the before and after period speed limit increase and the results are summarized in Table 4.

Table 4. K-S test results with test statistic, critical D , and corresponding p -values for available ATRs.

ATR#	Treated/Control Site	Test Statistic (D)	Critical D	p -Value	Statistically Significant Difference (Yes/No)
1	Control	0.0012	0.0013	0.99	No
2	Treated	0.0912	0.0050	0.046	Yes
3	Treated	0.0010	0.0012	0.99	No
4	Control	0.0019	0.0027	0.99	No
5	Treated	0.2723	0.0031	0.038	Yes
6	Control	0.0011	0.0017	0.99	No
7	Treated	0.2774	0.0019	0.042	Yes
8	Treated	0.1845	0.0024	0.046	Yes
9	Treated	0.0943	0.0018	0.039	Yes
10	Treated	0.2245	0.0036	0.042	Yes
11	Treated	0.3674	0.0035	0.038	Yes
12	Treated	0.0064	0.0007	0.041	Yes
13	Control	0.0032	0.0046	0.99	No

According to the results from Table 4, it is clear that the speed data for the majority of treated sites, which are affected by speed limit change, is differently distributed and there is a statistically significant difference between the before and after speed limit increase. However, there is only one treated site that belongs to ATR 3 and it shows that there is no statistically significant difference in the before period

compared to the after period. The reason for this matter could be because the sample size in the after period is much larger than the before period and it may not help to compare the significant difference easily. On the other hand, there is no statistically significant difference in the speed data distribution for control sites that are not affected by speed limit increase and it is understood that speed limit increase has had an effective impact on drivers' behaviors in the before period versus the after period.

4. Discussion and Conclusions

This study suggests that the impact of speed limit increase on the 85th percentile speed is considerable, and results showed that the speed limit change caused an increase in drivers' speed for the majority of the freeway section influenced by speed limit increase during the after period. Moreover, this increase was statistically significant in all of the places that ATRs did exist after the speed limit change. In addition, the 85th percentile speed and average speed increase among all sites have been statistically significant during the after period compared to the before period based on t-test results.

In order to have better results, the K-S t-test was applied and depicted the speed data distribution in the after period and was statistically different than the before period for the majority of the treated sections after speed limit increase. On the other hand, the speed data distribution for all of the control sites that were not influenced by speed limit increase did show no statistically significant difference between the before and the after period. The statistical significance of the change for all of the locations in the before and after analysis according to a two-tailed t-test could be because the sample size for this research is very large that any change in 85th percentile speed would be significant as recognized by previous research as well [10].

In this research, there were not enough ATRs at all of the treated and control sections influenced by the speed limit increase. If there are more available ATRs, the comparison of drivers' speeds for the sections with speed limit increase versus without speed limit increase could give more detailed results as the future research. Additionally, crash data analysis may be used in the future for comparing total and fatal and injury crashes in the before period versus after period. Overall, the speed limit increase has had significant increases in drivers' speed and caused a significant change in their behavior based on the new speed limit in Kansas. In conclusion, in order to have a safe and more sustainable transportation system, any new changes that are happening on the roadway sections are needed to be considered and new countermeasures could be applied if needed.

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