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FINAL REPORT

EVALUATION OF LONGITUDINAL CONSTRUCTION JOINTS ON TRAFFIC OPERATIONS AND SAFETY

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16 Abstract

Motorists generally follow the guidance provided by pavement markings, which are normally marked in coincidence with the longitudinal construction joints, when the markings are necessary. At some locations, however, there may be a difference between joints and markings, which may lead the motorists to follow joints instead of pavement markings. In the absence of detailed research on this topic, an effort was made in this study to evaluate the effects of unmatched longitudinal construction joints and pavement markings on the lateral positioning of vehicles. Sites with such characteristics were identified, and detailed data were collected at selected sites, using video camera techniques to capture movements of vehicles for longer durations. The video tapes were later reduced to extract necessary information. Distance from the pavement edge to the centerline of each vehicle, vehicle type, presence of vehicles in the adjacent lane, traffic volume, weather conditions, and vehicle movement were the main data parameters gathered while reducing the data. In addition, two surveys were also conducted to gather the opinions of practitioners.

Photographs of the vehicles traveling at several other locations, on the sections of the road which had mismatched joints and pavement markings were also taken. The data was analyzed to check for the impact of the non coincident pavement markings and longitudinal construction joints. A more rigorous statistical analysis was carried out for observations at one of the locations.

Based on the survey and analysis of field data, drivers' lateral position seems to be affected by unmatched joints and pavement markings. It is advisable to make efforts to avoid such occurrences.

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A Report on Research Sponsored By

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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ABSTRACT

Motorists generally follow the guidance provided by pavement markings, which are normally marked in coincidence with the longitudinal construction joints, when the markings are necessary. At some locations, however, there may be a difference between joints and markings, which may lead the motorists to follow joints instead of pavement markings. In the absence of detailed research on this topic, an effort was made in this study to evaluate the effects of unmatched longitudinal construction joints and pavement markings on the lateral positioning of vehicles. Sites with such characteristics were identified, and detailed data were collected at selected sites, using video camera techniques to capture movements of vehicles for longer durations. The video tapes were later reduced to extract necessary information. Distance from the pavement edge to the centerline of each vehicle, vehicle type, presence of vehicles in the adjacent lane, traffic volume, weather conditions, and vehicle movement were the main data parameters gathered while reducing the data. In addition, two surveys were also conducted to gather the opinions of practitioners.

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ACKNOWLEDGEMENTS

The authors would like to take this opportunity to recognize and thank those persons who provided information and assistance in preparing this report. First, we would like to thank James Brewer, Engineering Manager – State Road Office, for his overall guidance and advice. We would also like to thank Scott King, the project monitor, and Kelly Cool for their assistance, advice and patience as this project progressed. A number of others, including city and county engineers, KDOT Area Engineers and design engineers from AASHTO member states, provided data and commentary relating to the placing of longitudinal joints within or at the edge of lanes. Those who responded are identified by their respective agencies in tables in the Appendix of the report. Finally the authors would like to thank the manager of the Railroad Station Museum at Manhattan for allowing us to use the facility while photographing traffic on Fort Riley Boulevard in Manhattan and Jessica Landman for installation and operation of the photographic equipment at locations in and around Topeka, KS.

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CHAPTER 1 - INTRODUCTION AND BACKGROUND

1.1 Introduction

Drivers rely on a complex series of visual cues to safely navigate through the roadway system. Pavement markings and joints, arrows, words, symbol markings, and special markings constitute different types of messages that guide the motorists into positioning their vehicles on the roads. Longitudinal lines, such as center lines, lane lines, and edge lines, delineate vehicular paths of travel along the roadway by marking the center of road, lanes of travel, and edges of the pavement, respectively. Pavement edge lines provide a visual guide for confining vehicles to a travel lane. Several factors, such as speed, traffic composition, weather conditions, lighting conditions, roadway geometric design elements, drivers' physical condition, and personal attributes, may also have an influence on the lateral position of vehicles.

In situations where the pavement is wider than the paving machine, longitudinal construction joints occur. The pavement markings are typically expected to be marked coincident with the longitudinal construction joints. This does not mean that the pavement markings are applied directly over the joints. In some circumstances, however, the construction joints are placed wherever the edge of the paving machine might occur without regard to the pavement markings. Under these conditions, motorists have additional factors to consider while traversing that section of the roadway.

This study was primarily conducted to evaluate the effects of longitudinal construction joints on traffic operations.

1.2 Background

Cracks occur in Portland Cement Concrete Pavement (PCCP) in a number of ways. The least desirable way is caused by random cracking, which occurs due to the inability of the slab to withstand the stresses incurred, either because of natural settling, heavy loads or failure of the sub-base. All the pavements generally crack at random positions, if the slab is not purposely weakened at specific locations. Transverse joints are provided perpendicular to the centerline of the roadway. Longitudinal joints are provided parallel to the centerline of the lane, either within the lane or at the edge. Longitudinal joints are the only type of joints that will be considered in this report. Longitudinal joints are either sawed into the finished pavement soon after setting, or are the result of being at the edge of a lane pour (construction joint).

Whether the crack occurs at a planned location or in a random pattern, it is necessary to fill the crack with a material that will prevent water from penetrating through the pavement and weakening the base material. A number of different materials have been used to fill cracks but the cheapest and most reliable seems to be a bead of asphalt poured into the crack. The fill material is visually different from the pavement and creates a contrast that can attract the driver's attention. When the pavement is new, the fill material is barely visible and the authors observed little effect on the driver. As the pavement ages, the joints deteriorate and it requires more material to seal the joint, thus making it more noticeable. If the joints show significant deterioration, patching material will be used to fill the void, causing even more visual effects.

On sections of roadway with no changes in cross-section, the longitudinal joints are almost always found at the edge of the lane. It is common practice to pave an entire lane in these sections. On ramps, particularly curved ramps that require a wider cross-section, longitudinal joints will be required to prevent random cracking. Often this will be accomplished with one construction joint and one sawed joint.

Some state transportation agencies will allow the contractor to put the construction joint at the center of the cross-section of the lane and eliminate the need for a sawed joint. This practice, with one exception, has not been allowed by the Kansas Department of Transportation (KDOT) on the State Highway System. A reconstructed section of I-35 from US-75, east, now has a joint in the center of the ramps of several interchanges. Whether or not to allow this method of paving ramps became the motivation behind the research documented by this report.

CHAPTER 2 - LITERATURE SEARCH

The research team found numerous reports relating to the deterioration of longitudinal joints, both on highways and airport runways. These reports included evaluations of aggregates, sealing materials, and repairing of longitudinal joints. However, there appeared to be little, if any, research conducted on the operation and safety of unmatched longitudinal construction joints and pavement markings. In lieu of published research, the study team decided to analyze the standard specifications of the various departments of transportations, assuming that these specifications reflected the experiences of these agencies. The specifications of 35 state departments of transportations contained provisions for the placement of longitudinal joints at the edge of the lane, although some allowed some discretion subject to the approval of the engineer (assumed to be the agency's project engineer). No information was obtained from three states. A summary of the standard specifications is provided in the Table 2.1.

Table 2.1: Summary specifications for the location of pavement joints with respect to markings

Description	Number
Agencies preferring to keep joints at edge lines or centerline of the travel lane	21
Agencies requiring joints to be concurrent with edge of lane	14
Total number of agencies having specifications on positioning of longitudinal joints with respect to pavement markings	35
Agencies that did not specify location of joints	12

The specifications of the transportation agencies on the positioning of joints with respect to the pavement markings are documented in the Appendix A.

CHAPTER 3 - SURVEY OF TRANSPORTATION PROFESSIONALS

Two questionnaires were developed in cooperation with the road design office of the KDOT. One questionnaire was prepared for gathering opinions from the KDOT area engineers and city and county engineers within Kansas. The other questionnaire was sent to AASHTO members. A copy of the questionnaires is included in Appendix B. The purpose of the questionnaires was to determine if the respective agencies currently require the joints to be placed at the edge of lanes, whether they were aware of existing mismatched joints located within the lane and whether they experienced operational problems at these locations.

As the questionnaire was being developed, the Project Monitor decided to use an online service to which KDOT had subscribed, to obtain responses to the survey. This service is called “Survey Monkey” and can be found online at www.surveymonkey.com. An email was sent to the participants and they were requested to respond online. The responses were then retrieved by KDOT staff. The resulting files were large matrices with the various questions stored in columns and the responders in rows. There was a separate matrix for Kansas respondents and for other AASHTO member states. The questions and are included in Appendix B.

The comments of the responding states varied widely. The general indication was that mismatched joints and pavement marking should be avoided. Several states expressed safety concerns but did not have specific examples. It appeared that they were making an assumption that there could be safety problems. Others indicated that they experienced no operational nor safety issues.

Several states expressed the concern of having the joints located in the wheel path, causing excessive joint deterioration and possible safety concerns. One state indicated that if they could not match, the joint should be placed in the middle of the lane. This would be consistent with the comment that the joint should not be placed in the wheel path.

Several states misinterpreted the question by indicating that the joints and markings should not be matching but then further indicated that they should be offset by 3 to 4 or 6 inches.

The comments from city, county and KDOT field personnel were similar to those from other states. Several indicated that they were not aware of any problems while some indicated that deteriorated joints would make them more visible and could be confusing. One person indicated that he preferred that joints and pavement marking match on curves.

CHAPTER 4 - DATA COLLECTION AND ANALYSIS

The type of analysis differed from location to location. The most detailed analysis was applied to the data collected on Fort Riley Blvd, near the Kansas River Bridge in Manhattan, KS. Data were collected at two different times using two different camera systems at this location. The first session was done when the stripes were extremely weathered and the second session was taken after the stripes had been repainted. At several locations, it could be seen from data collected over a one hour period, how drivers reacted to the location of the joints. At other locations, the research team observed the action of the driver without collecting any quantified data. The discoloration of the pavement, where the vehicles traversed, provided a clue to the reaction of the driver.

4.1 Fort Riley Boulevard, Manhattan, KS

The principal means of collecting data for this research was through the use of cameras. The first set of data collected on Fort Riley Blvd, in Manhattan, was made with a camera with a fish-eye lens placed high on a light pole next to the roadway and the images of the vehicles were recorded on a video cassette recorder (VCR). These images were viewed and measurements were taken of the location of the vehicle in the lane as it moved through the field of view. The camera was placed over the west bound lane of K-18 (Ft Riley Blvd) just southwest of the northwest end of the Kansas River Bridge and near the entrance of the refurbished railroad depot as shown by the arrow in Figure 4.1.

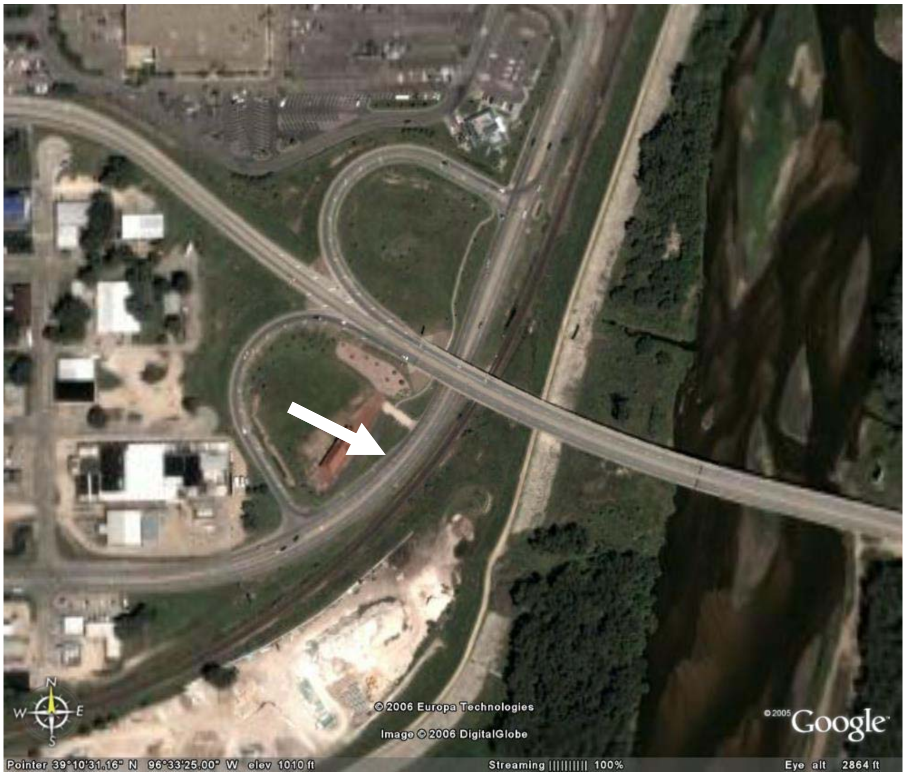

Figure 4.1*:* Fort Riley Boulevard, Manhattan, KS

This location was chosen because the longitudinal joints crossed the lanes diagonally toward the median near the entrance to the railroad station. Additionally, a new lane starts in the middle of the outside lane and continues as the exit ramp to southbound K-18/K-177 over the bridge. When discussing the nature of this research, local residents, local police, and a highway patrolman all mentioned this site as being very confusing.

The observations at Ft. Riley Blvd. were recorded twice, during the project. An outdoor security camera was used to record the vehicles at this location, to conduct a before and after study. The camera was fixed to the handrail of the Kansas River Bridge, near the site. The position of the camera installed on the Kansas River Bridge is shown by an arrow mark in Figure 4.2.

Figure 4.2*:* Security Camera on Handrail of Kansas River Bridge

A camera with a fish-eye lens was also used at the site for recording the observations. It was mounted on a utility pole as shown in Figure 4.3 for capturing the vehicular position/location for longer durations.

Figure 4.3: Camera with fish-eye lens mounted on a utility pole at Ft. Riley Blvd

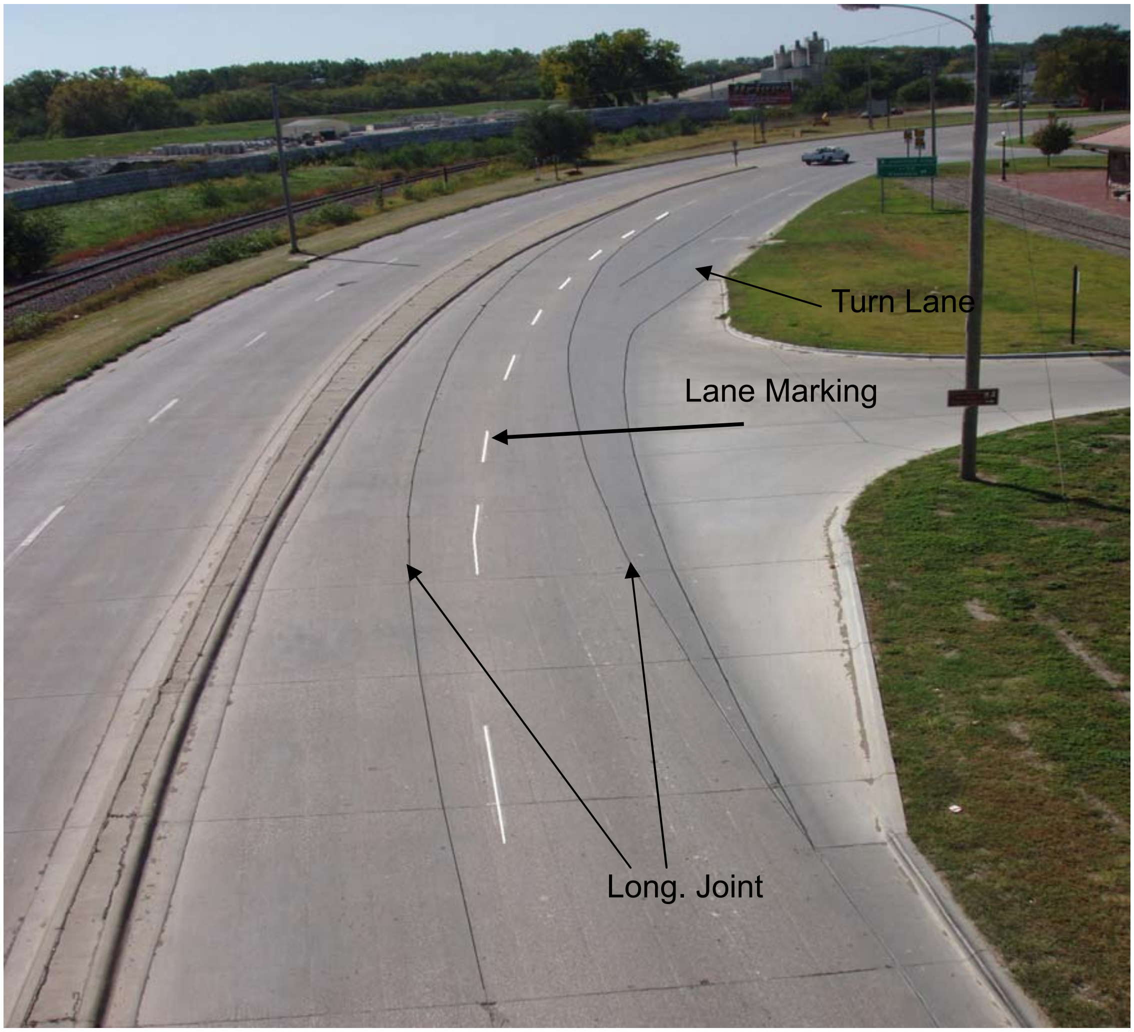

Figure 4.4: Westbound K-18 (fort Riley Blvd.)

Figure 4.4 shows a picture taken from the Kansas Avenue Bridge. The view of the joints has been enhanced by the addition of black lines on the above photo as indicated by the black arrow heads. The lane markings have also been enhanced in the photo by the addition of a broken white line.

4.1.1 Before and After Restriping

As was mentioned earlier in this chapter, two sets of video were collected at this location. With the exception of the analysis of the effect of the lane striping, all the detailed analyses were made of the earlier set of video.

During the first round of data collection, the striping was almost completely worn away. The location was re-striped in June of 2007 and the last round of data collection was done following the restriping.

The summary statistics of the observations, before and after the restriping, are reported in Table 4.1.

Table 4.1: Summary statistics of the before and after study at Ft. Riley Blvd.

Description	**Condition**	**Sample Size**	**Mean* (feet)**	Std. Dev. (feet)
All vehicles	Before	2,007	8.69	0.84
	After	1,605	8.63	0.85

*Mean distance is measured from the outside curb to the center of the vehicle.

Surprisingly, there is very little difference in the location of vehicles in the lane between the two conditions. Both the mean location of the vehicles within the lane and the deviation about the means are nearly identical. It would appear that at this location, the lack of highly visible lane striping did not adversely influence drivers.

4.1.2 Vehicles in Adjacent Lane

It is assumed that drivers will steer to the right if there is a vehicle in the lane beside them on the left. The decision as to whether the location of the vehicle in the adjacent lane is influencing the driver is subjective. The following table summarizes the results found at this location.

Table 4.2: Summary of the data classified on the basis of vehicles in the adjacent lane

Distance* to the centerline of vehicles (ft)	All vehicles			
	Without vehicles in adjacent lane		With vehicles in adjacent lane	
	Number	%	Number	%
3-4	56	0.5	12	0.8
4-5	1441	11.5	242	16.6
5-6	1784	14.1	243	16.6
6-7	2920	23.2	369	25.3
7-8	2320	18.4	249	17.0
8-9	2808	22.3	252	17.3
9-10	715	5.6	57	3.9
10-11	359	2.9	26	1.8
11-12	122	1.0	8	0.5
12-13	51	0.4	1	0.1
13-14	8	0.1	0	0.0
14-15	7	0.1	0	0.0
Total	12591	100	1459	100

* Distance from outside curb

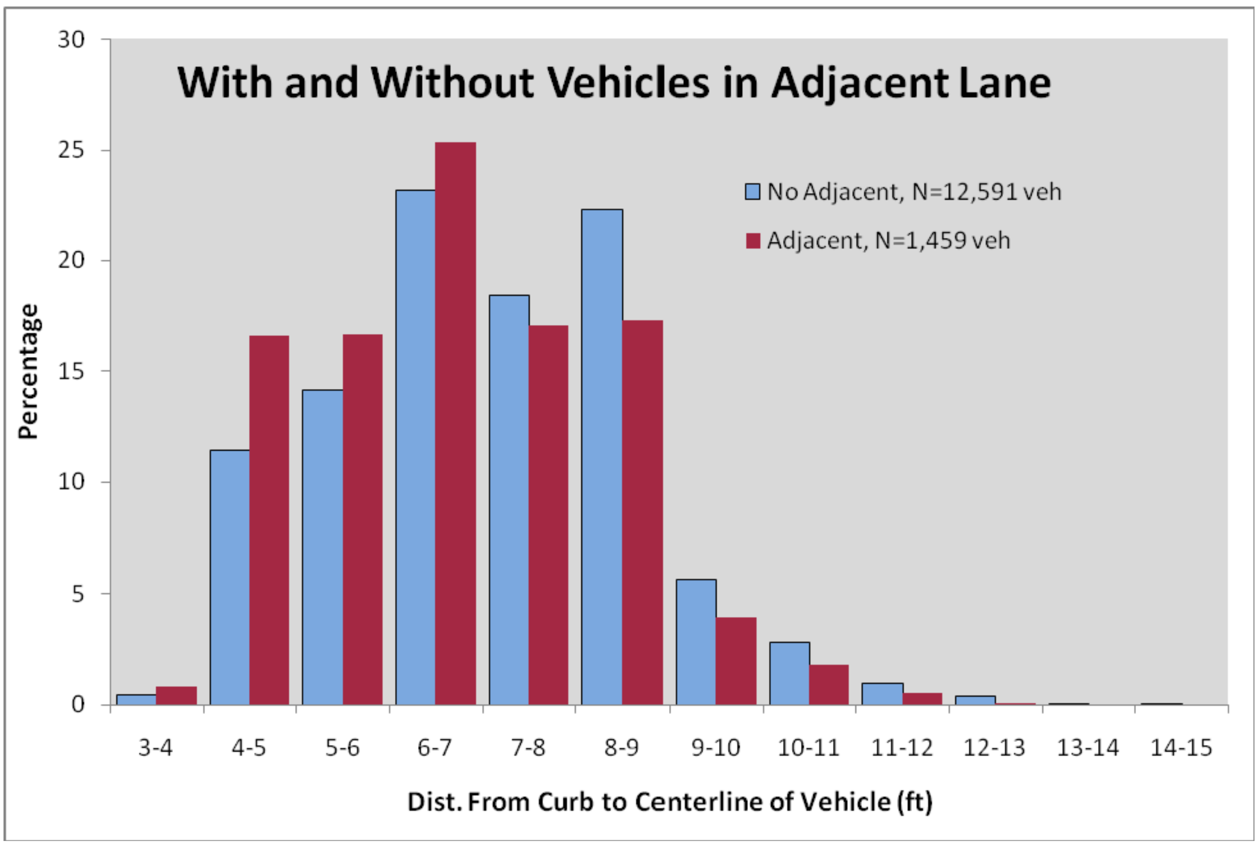

Figure 4.5: Histogram of the data, with and without vehicles in the adjacent lane

It is assumed that the vehicle will stay farther to the right in the right (outside) lane if there is a vehicle near them in the adjacent (inside) lane. This would suggest that the adjacent vehicle has more influence on the driver in the right lane than does the location of the longitudinal joint. In viewing the histogram in Figure 4.5, it can be seen that the "No Adjacent" bar is taller than the "Adjacent" bar for distances greater than the 7-8', thus supporting this assumption. However, assuming that the average vehicle is six feet wide, 17.3% of the drivers (8-9') in the outside lane are placing the driver side wheels almost directly on the center stripe when there is a vehicle in the adjacent lane. There were even 92 drivers (9-10' and above) that had placed their driver side wheels in the adjacent lane, even when there was a vehicle adjacent to them. There were no crashes that occurred, but there certainly is a strong potential for side-swipes or for head-on crashes if the vehicle in the inside lane would jump the curb and hit oncoming traffic. The data supports the conclusion that either the drivers just are not turning enough to stay in their lane or they are being misled by the location of the longitudinal joint.

The Ft. Riley Blvd. data has also been analyzed statistically on the basis of with and without vehicles in the adjacent lane by vehicle type as well as total vehicles. The mean, standard deviation, t-value and corresponding p-values of the t-test are shown in the Table 4.3. Based on these analyses, the differences of location of total vehicles and vans within the lane in not significantly different whether or not there is a vehicle in the adjacent lane. Passenger cars, pickups and heavy trucks show a significant difference in their location within the lane when there is a vehicle in the adjacent lane.

Table 4.3: Summary statistics of the data, with and without vehicles in the adjacent lane

Description	Vehicles in adj. lane *	Sample Size	Mean (feet)	Std. Dev. (feet)	*F*-test		*t*-test	
					F value	Pr.>*F*	*t*-value	Pr.>*t*
Total vehicles	No	12,591	7.10	1.61	1.11	0.0085	9.43	<0.0001
	Yes	1,459	6.70	1.53				
Passenger cars	No	5,286	6.40	1.44	1.12	0.0623	7.17	<0.0001
	Yes	592	5.96	1.36				
Vans	No	3,663	7.46	1.50	1.22	0.0102	6.13	<0.0001
	Yes	392	7.01	1.36				
Pickups	No	2,976	7.59	1.48	1.11	0.1972	4.83	<0.0001
	Yes	376	7.20	1.41				
Heavy Trucks	No	666	8.56	1.61	1.23	0.1976	3.04	0.0024
	Yes	99	8.04	1.46				

***** No-Without vehicles in the adjacent lane, Yes-With vehicles in the adjacent lane

4.1.3 Influence of Adverse Weather

One would expect that during adverse weather, when the roadway is wet or partially covered with snow, driving patterns would change. Measurements were taken from photos to compare the paths of the vehicles during wet weather conditions with dry roadway conditions. The wet pavement condition was caused by rain changing to snow. The snow accumulation was minimal, but may have been heavy enough to obstruct the view of both the joints and the striping for the driver for a short time during the data collection period.

Figure 4.6 shows the percent of vehicles that chose paths at the various distances from the curb.

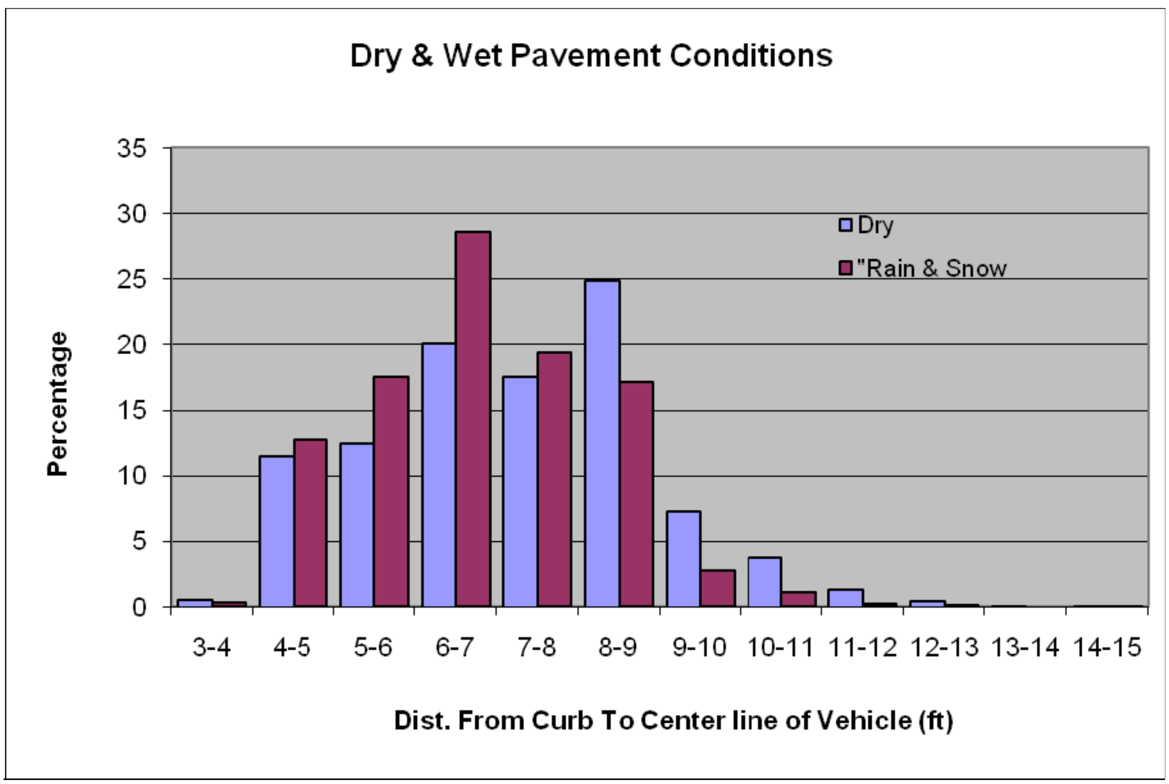

Figure 4.6: Distribution of vehicles under dry and wet pavement conditions

The histogram above (Figure 4.6) shows that the drivers of the vehicles tended to drive closer to the right curb during the adverse weather conditions. The average distance from the curb to the center-line of all vehicles was 8.1 feet on dry pavement and 7.5 feet on wet pavement. This could be because the driver cannot see the marking or the joints so they use guide of the nearest curb. The calculated mean distance to the centerline of vehicles, by vehicle type, and classified on the basis of weather conditions is indicated in the Table 4.4. For each vehicle type, including total vehicles, the mean distance to the center of the vehicle is approximately 0.5 feet closer to the right hand curb for the wet weather conditions.

Table 4.4: Mean distance to the centerline of vehicles under different weather conditions

S.No	Description	Dry Pavement		Wet Pavement	
		Number of vehicles	Distance (Feet)	Number of vehicles	Distance (Feet)
1	All vehicles	8,519	8.07	5,531	7.52
2	Passenger Cars	3,588	6.52	2,290	6.10
3	Vans	2,282	7.66	1,773	7.10
4	Pick-ups	2,142	7.75	1,210	7.21
5	Heavy Vehicles	507	8.79	258	8.13

4.1.4 Comparison of Turning Vehicles to Those Continuing on Fort Riley Blvd.

The other comparison of vehicles was on the basis of movement. Vehicles were observed going straight (continuing west on Fort Riley Blvd.), and making a right turn (turning onto the SB Ramp). The calculated mean distance of different type of vehicles classified on the basis of movement is given in Table 4.5.

Table 4.5: Mean distance of vehicles classified on the basis of movement

S.No	Description	Going straight		Taking a right turn	
		Number of vehicles	Distance (Feet)	Number of vehicles	Distance (Feet)
1	All vehicles	8,714	7.17	5,336	6.90
2	Passenger Cars	3,657	6.49	2,221	6.14
3	Vans	2,552	7.53	1,503	7.23
4	Pick-ups	2,052	7.64	1,295	7.42
5	Heavy Trucks	448	8.44	317	8.58

From Table 4.5, it can be inferred that the most vehicles taking a right turn were observed to be traveling closer to the right hand curb when compared to the vehicles going straight. While the mean distance is less for all vehicles, except heavy trucks, the location of the joints may have little to do with the resulting data. Right turning vehicles could have already been starting their turn because the entrance to the railroad station and the beginning of the right turn ramp provided an opportunity to start their maneuver within the area that the measurement was taken. The data would seem to support the fact that heavy vehicles require a larger radius for turning their trailer unit. Hence, their mean distance to the centerline of travel while taking a right turn is observed to be greater than those going straight.

4.2 MacVicar Avenue, Topeka, KS

A small security camera was used in various locations around Topeka, KS. The first site was on MacVicar Avenue, about 0.20 miles south of I-70. This section is a city street that was constructed approximately 40 years ago. The east half of the street (northbound) was constructed with a permanent curb. The west side of the street (southbound) was constructed wide enough to provide for a two lane street with a temporary asphalt curb. Because the remainder has not been constructed, the centerline joint is near the center of the southbound lane. The effect of the location of this joint was the reason this location was included in the research project.

Data was gathered at this location for two hours. The data from the video camera was recorded on a DVD recorder and the video was viewed on a TV. A clear sheet of material with a grid drawn on it was placed on the screen. The grid was calibrated to the distance from near the west curb-line to the longitudinal joint. Because the asphalt curb was badly deteriorated, there was no clear-cut line from which to measure.

Figure 4.7: MacVicar, looking North toward I-70

The data corresponding to 329 vehicles of all types were collected at this location. The distance was measured from the outside of the passenger side tires of the southbound vehicles to a point that was assumed to be the curb-line. The analysis differed from that of previous locations in that the joint was parallel to the roadway for some distance and was in or near the wheel path of the passenger side tires, depending on where the driver chose to drive. The longitudinal joint is located at a distance, slightly less than 6 feet from the curb line. Vehicles which had their passenger side tire positioned between 2.5 feet to 5.0 feet from the curb line were straddling the joint. Drivers traveling with their passenger-side tire, 5.5 feet from the curb line placed their tire directly on the joint, and those traveling at 6.0 feet or more from the curb line had both wheels between the joint and the center-line strip. Those vehicles traveling 7.5 and 8.0 feet from the curb line had their left wheels on or over the center-line strip.

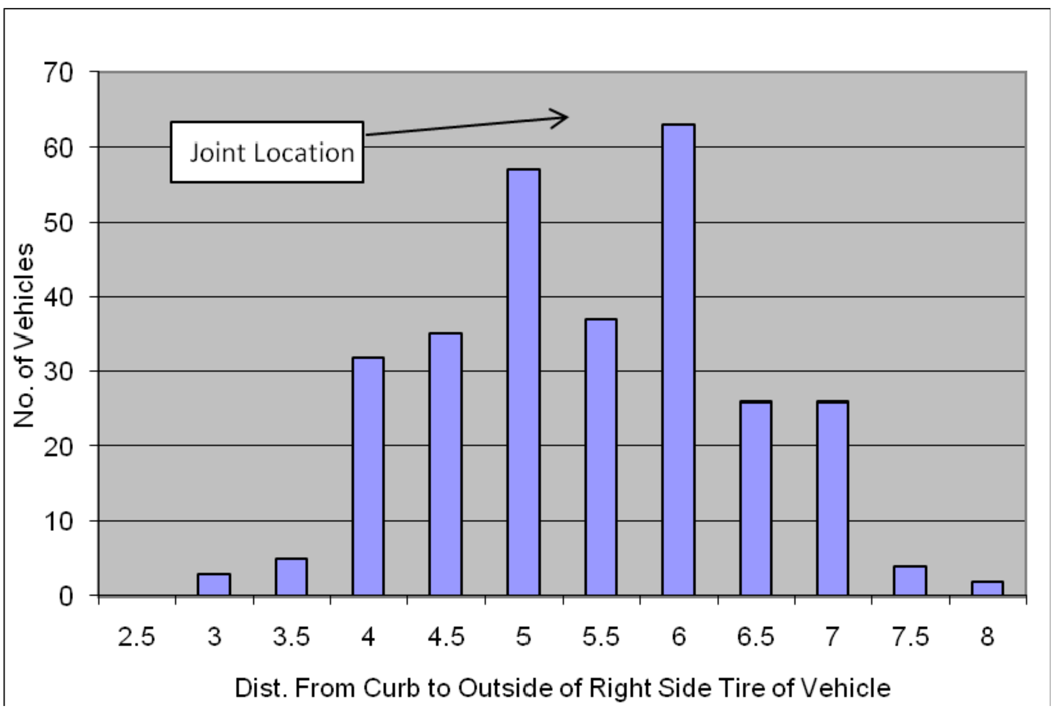

Figure 4.8: Distribution of all the vehicles traveling at MacVicar Avenue

The above histogram shows the results of the analysis of the data of all the 329 vehicles. As different types of vehicles were found to be traveling at this site, data corresponding to large vehicles, including all trucks, were separated from the dataset, which accounted for 39 vehicles. 290 passenger vehicles were observed to be traveling at this location during the time of data collection. A histogram was plotted for large vehicles including all trucks are shown in Fig 4.9.

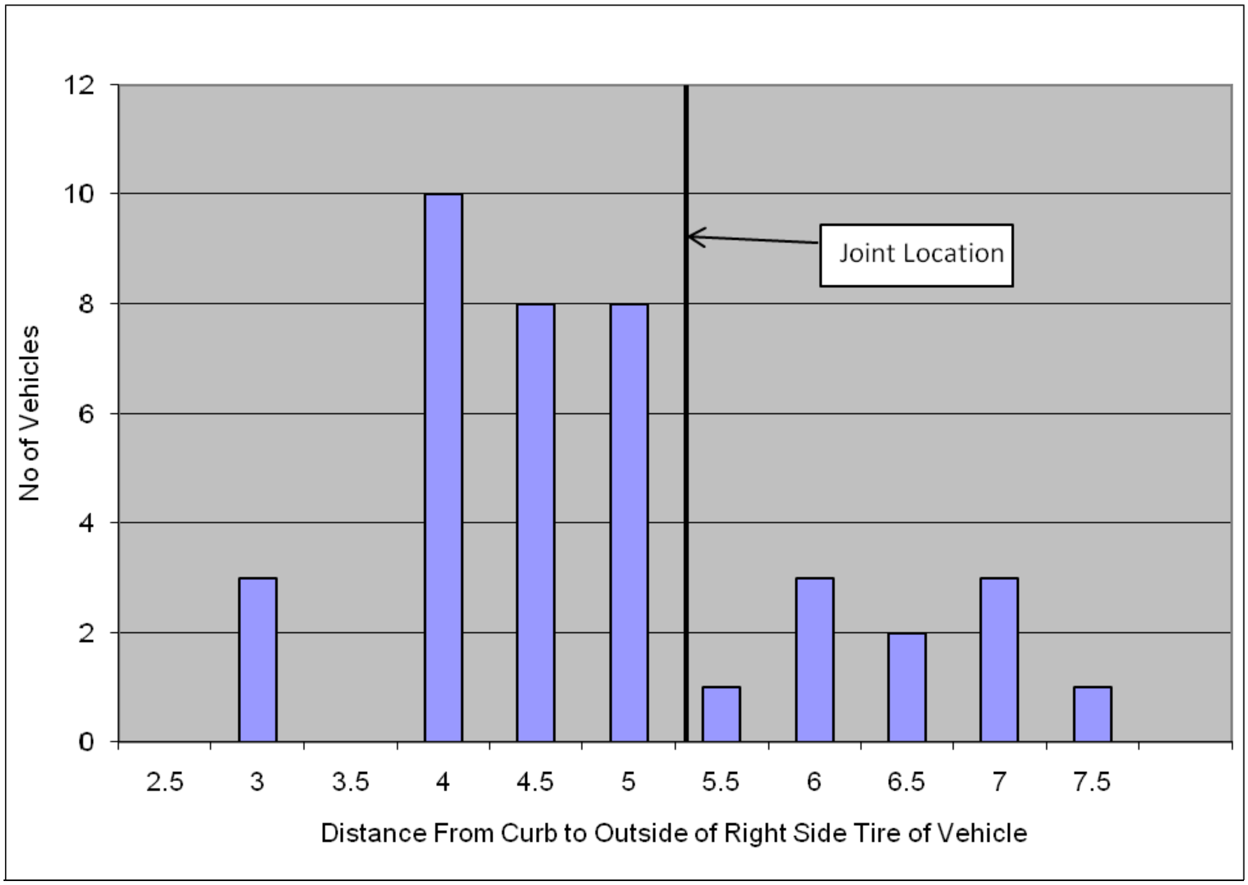

Figure 4.9: Distribution of large vehicles traveling at MacVicar Avenue

As the trucks and other large vehicles tend to be wider than the passenger vehicles, most of them were observed to be straddling the joint. From the histogram, it is evident that around 29 of the 39 vehicles were traveling at a distance of 2.5 feet to 5.0 feet from right curb of the road.

4.3 K-4 Interchange, Topeka, KS

The prior two locations were chosen because they had been identified as confusing to motorists. This location was chosen to determine where drivers would locate themselves on a newly constructed section of roadway with a noticeable longitudinal joint within the driving lane. The I-70/K-4/Kansas Turnpike (KTA) Interchange is a well-marked, complex interchange with numerous ramps at various locations. Photos were taken on the southwest bound K-4 to I-70 ramp, a fairly straight section of roadway, just beyond where a ramp exits to the left toward westbound KTA, as shown in Figure 4.10.

Figure 4.10: I-70/K-4/KTA Interchange, East Side of Topeka

Figure 4.11 shows the location of the camera, atop the sign in the gore area. The camera transmitted the video to the receiver located in a vehicle parked in the median beyond the sign.

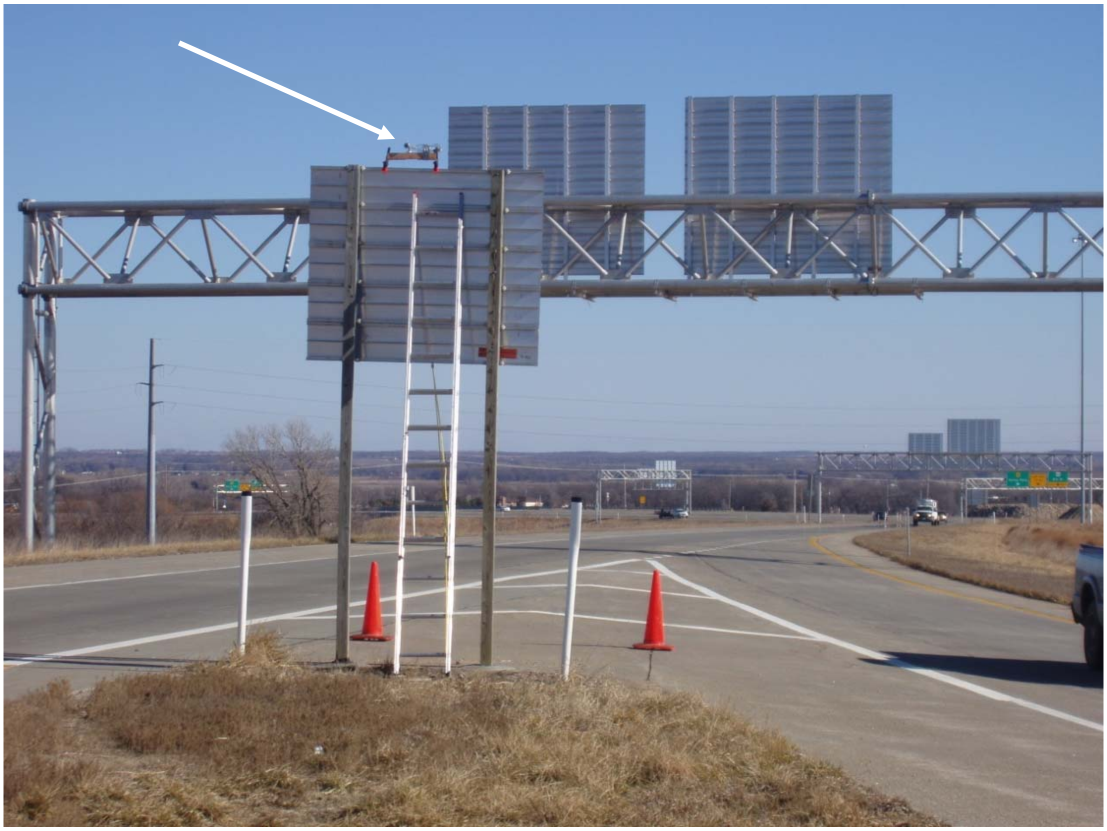

Figure 4.11: Camera fixed on a signboard near the I-70/K-4/KTA Interchange

The ramp included a 14 foot lane and a left and right shoulder. Figure 4.12 shows the configuration of the joints and shoulder striping at this location. At this location, measurements were made from the yellow strip at the left side of the lane to the outside of the tire on the driver's side (left) of the vehicles.

Figure 4.12: View of joints and pavement markings on K-4 WB Ramp

The longitudinal joint was located 4 feet away from the left stripe of the pavement. A total of 100 vehicles were observed to be traveling under both the daytime and nighttime conditions. Under the daytime conditions, 51 vehicles were seen traveling with a mean and standard deviation of 5.9 feet and 1.24 feet. respectively. Figure 4.13 shows the distribution of vehicles across the ramp. Four of the 51 vehicles were driving with the left tire directly on the joint. Assuming a vehicle width of 5.5 to 6.0 feet, those four vehicles were driving in the center of the marked lane. The remaining 47 were driving to the right of the center of the marked lane. This would indicate that the drivers were either influenced by the longitudinal joint or they tend to driver closer to the right side of the lane. The histogram of the vehicles under the daytime conditions is shown in Figure 4.13.

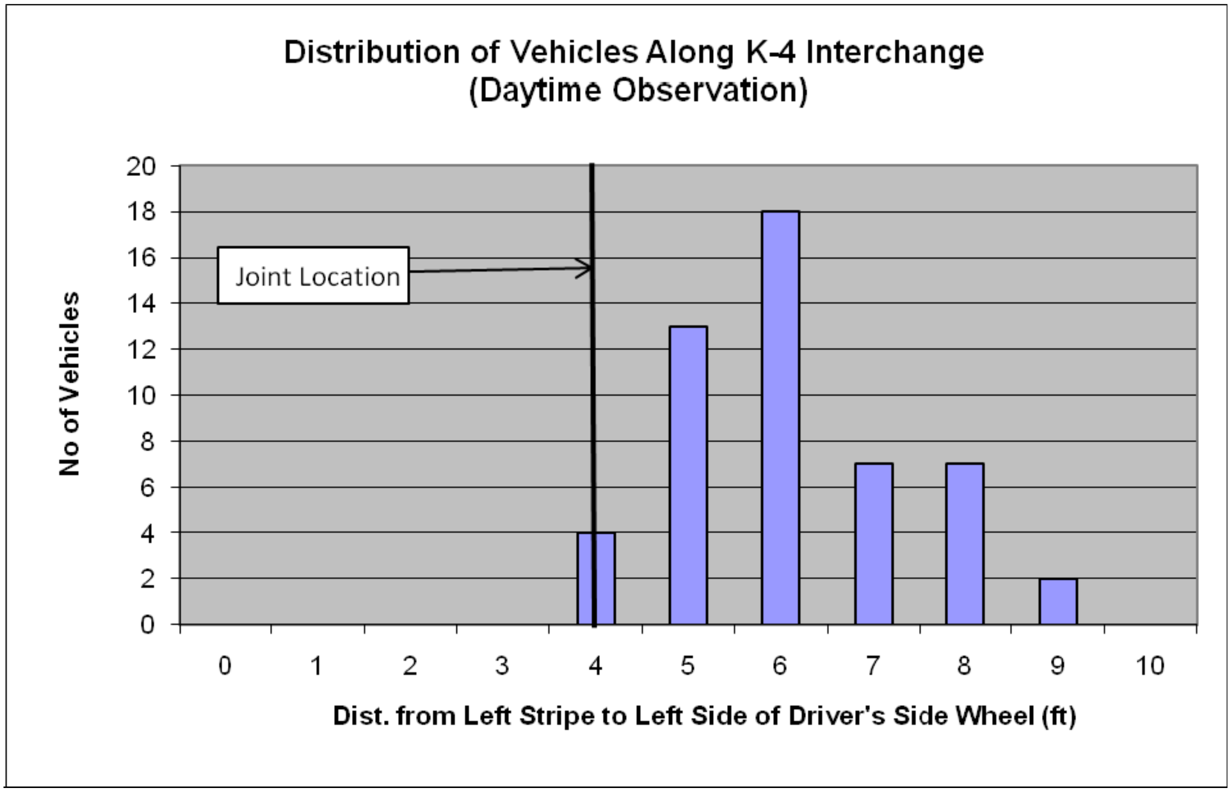

Figure 4.13: Distribution of the vehicles under daytime conditions

A total of 49 vehicles were considered for analysis under the nighttime conditions. The mean and standard deviation of these 49 vehicles were calculated as 6.3 feet and 1.61 feet. A graph was plotted by considering the same variables as that of the daytime observations and the frequency of the vehicles was thus calculated. The average nighttime drivers moved even farther to the right, but with greater deviation. This would indicate either a greater influence from the longitudinal joint or a lesser concern for the outside lane line on the right. The histogram of the vehicles under the nighttime conditions is shown in Figure 4.14.

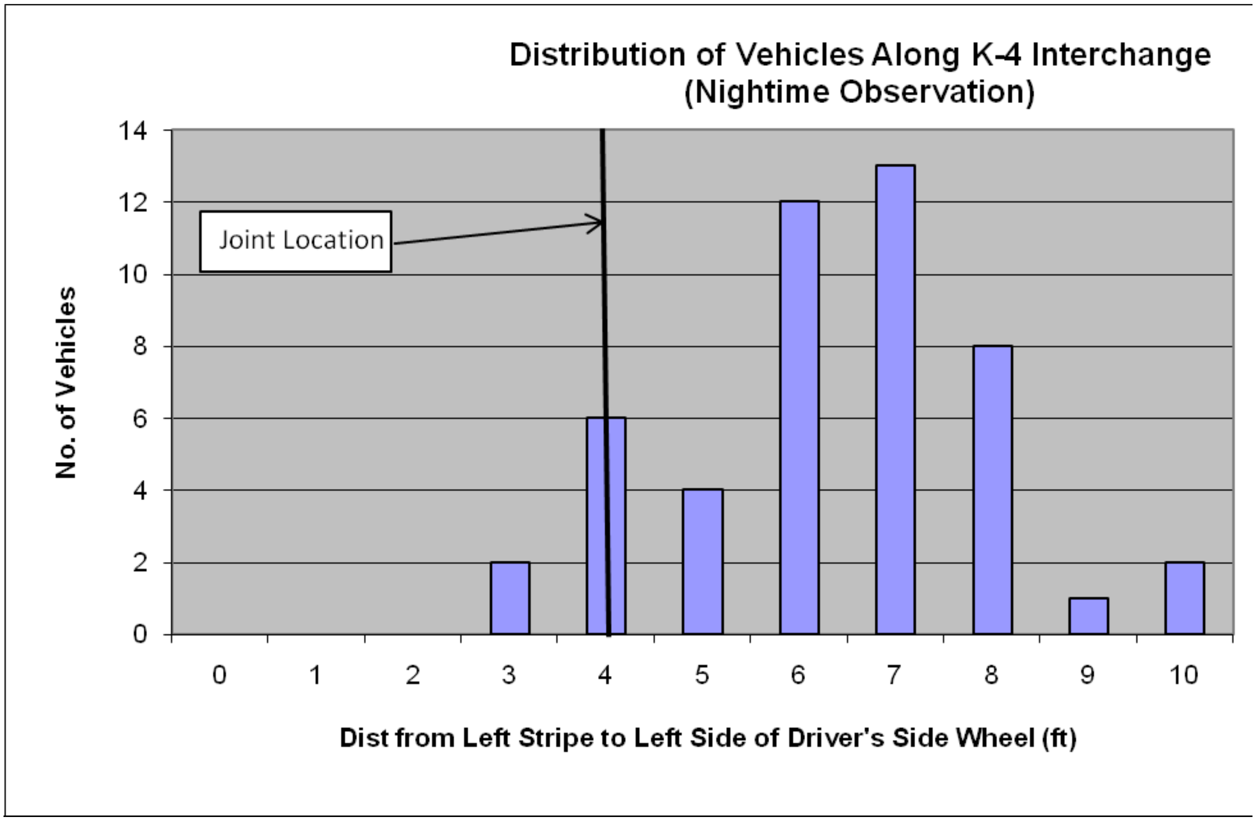

Figure 4.14: Distribution of the vehicles under nighttime conditions (K-4 Interchange)

4.4 I-35/US-75 Interchange, "Beto Junction"

The ramps at this interchange have been reconstructed and paved as part of an interstate reconstruction project on I-35. During construction, KDOT's field personnel approved a request by the contractor to construct the longitudinal joints down the center of the ramps. By placing a joint in the middle of the ramp, the paving operation could be accomplished in one pass, thus saving the contractor time and money. There is a large and very busy truck stop just south of I-35, on the east side of US-75. The volume of trucks entering and exiting at this interchange is extra-ordinarily high for a rural diamond interchange. Judging from the current traffic count map, approximately 750 heavy commercial vehicles (trucks) are exiting I-35 on the westbound ramp and 450 of these trucks are entering and leaving the truck stop. The trucks using the westbound off-ramp, indicated by the white arrow on the photograph below, must make a left turn to proceed to the truck stop. The reconstruction of pavement to the east was completed before the resurfacing was complete west of the interchange. The striping of the ramps was not undertaken until the project to the west was completed. The first series of pictures taken at this location were taken after a right-shoulder rumble strip was added but before the final lane striping was complete. A second series of pictures was taken after the striping was completed.

Figure 4.15: I-35/US-75 Interchange showing truck stop

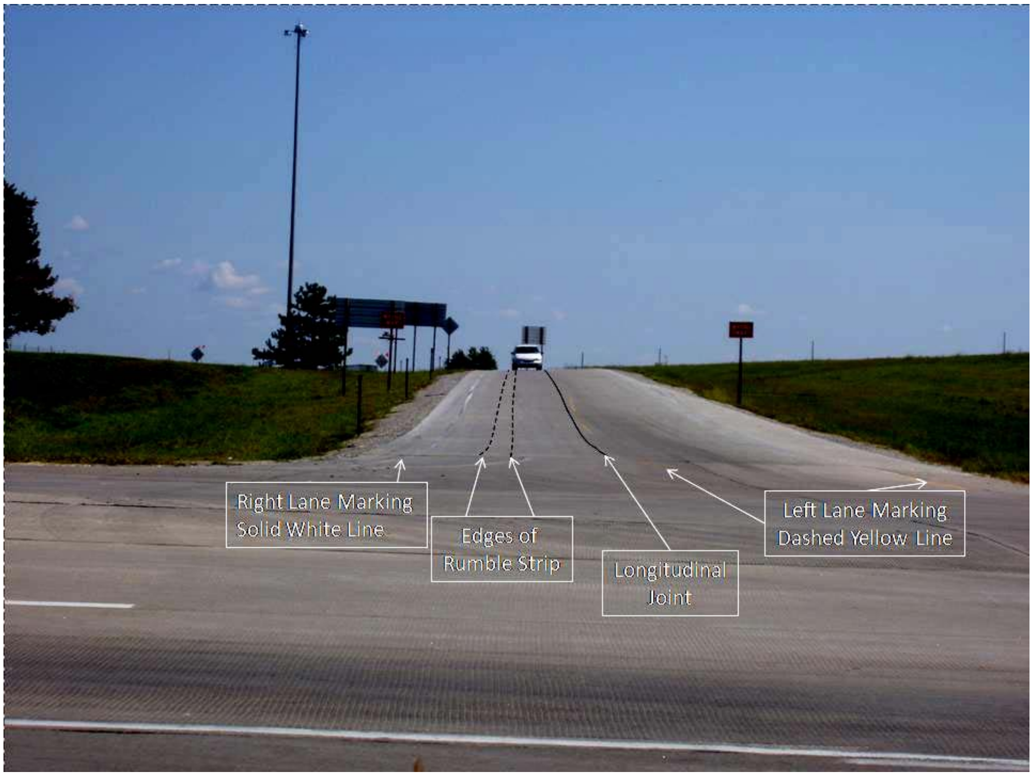

Figure 4.16.1: Ramp before final striping

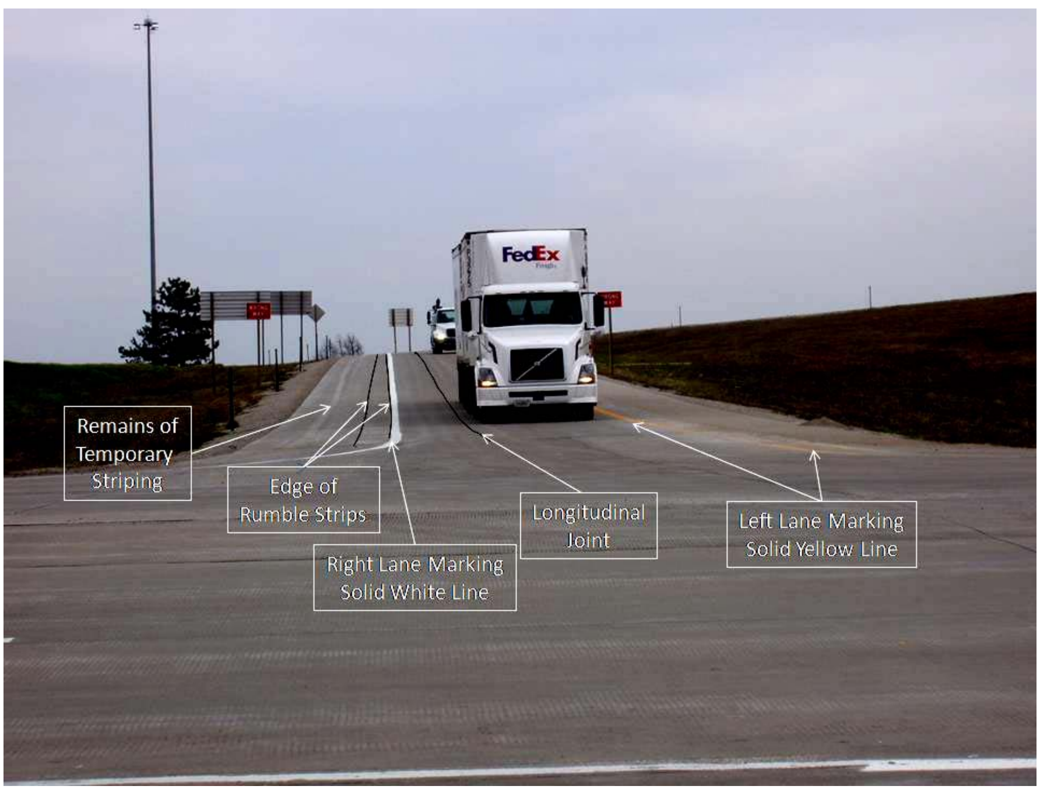

Figure 4.16.2: Ramp after final striping

The research was carried out to observe the position of vehicles before and after the application of pavement markings. As can be seen in the photograph taken before the permanent marking was applied, the temporary striping is almost completely worn away, except for one strip outside of the rumble strip, near the outside of the slab. In the lower photograph, taken after the permanent striping was applied, the right hand strip is white and placed just inside the rumble strip. However, the faded strip, farther to the outside is still barely visible and was used for measurement.

A still camera was used for taking the pictures of westbound vehicles exiting I-35 at this location. The distance to the front right passenger side of vehicles from the faded pavement markings was measured from the photographs. The distance measured using a scale fixed on the monitor of a computer was converted into the actual field dimensions. Photographs of 45 vehicles were used to analyze the before condition. The position of rumble strips, longitudinal joints and expected centerline of vehicles was plotted on a graph. As could be expected, the vehicle tended to be distributed all across the exit ramp. Surprisingly, approximately 20% of total vehicles were observed to be traveling with their right-side tires on the rumble strips as they proceeded down the ramp. The distribution of the vehicles across the width of the ramp is shown in Figure 4.17.

The final pavement markings were placed according to the plans. Photographs of 62 vehicles were taken after the lane marking were placed. The outside strip and the center of the marked lane were added to the histogram. It was observed that 34% of vehicles were traveling exactly over the joints which were located at 8.50 feet from the faded pavement markings. The graphs of the vehicles plotted under the before and after condition are shown below

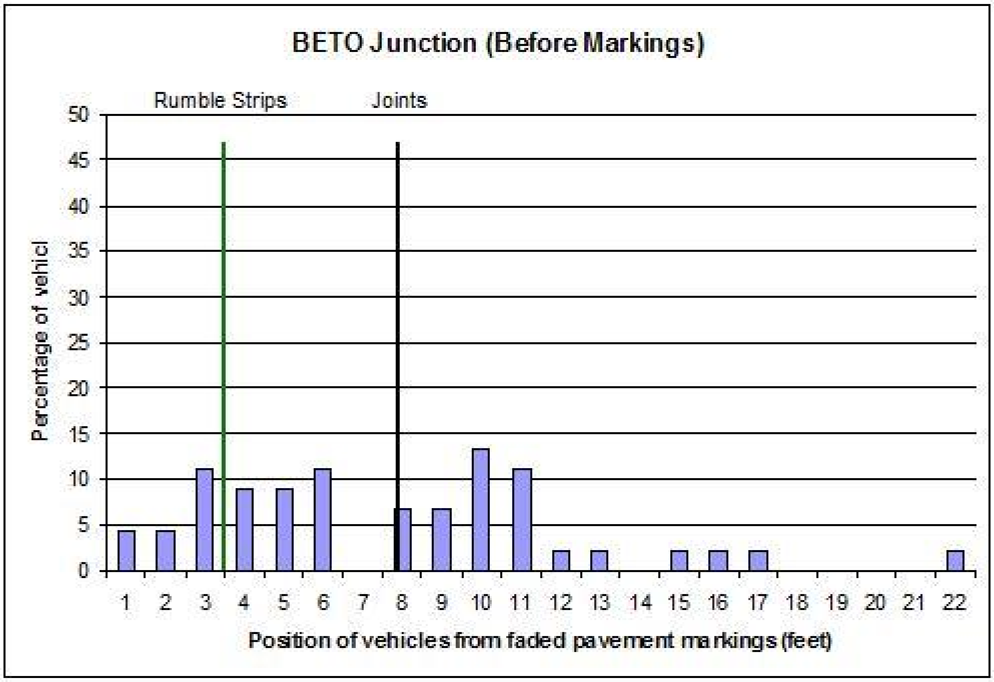

Figure 4.17: Distribution of vehicles with faded pavement markings

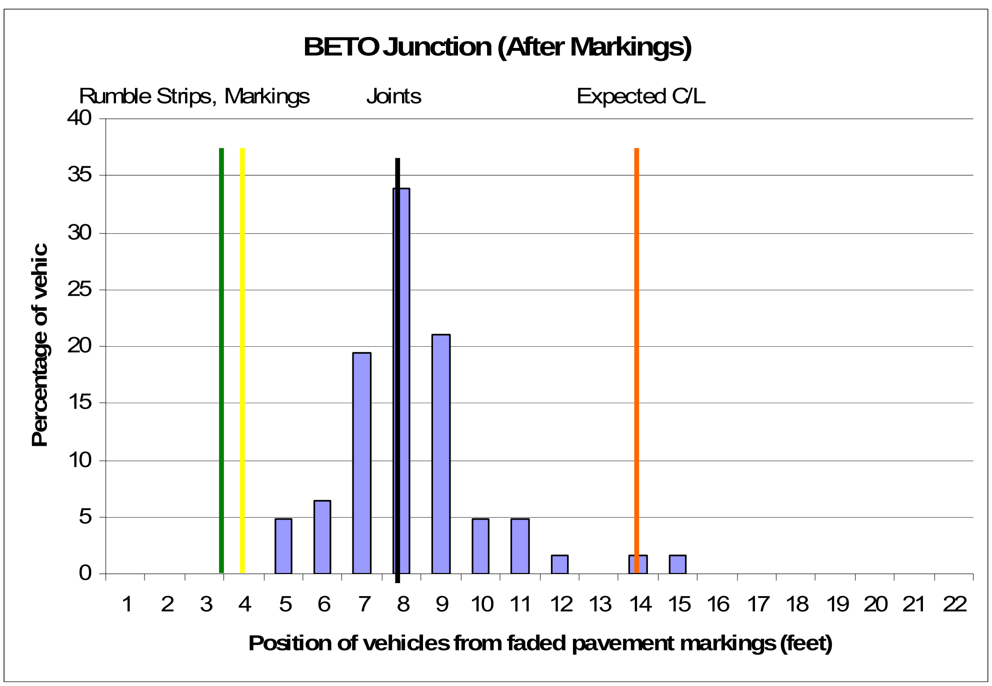

Figure 4.18: Distribution of vehicles at Beto Junction with newly laid pavement markings

Under the condition of newly laid pavement markings, 34% of the right-side tires were tracking exactly over the joints. KDOT's Geotechnical Unit expressed an opinion that such a situation is undesirable for the pavement performance. They indicated that they wanted to see tire paths at least one foot from a longitudinal joint.

An analysis of the previous two graphs indicates that the striping of the ramp produced the desired results of reducing the deviation of the paths of the vehicles traveling down the ramp towards the intersection with US-75. In doing so, it concentrated the wheels loads directly over the longitudinal joint. While there is no current adverse operational or safety problems caused by placing the joint at the center of the paved portion of the ramp, joint deterioration will likely be accelerated, if the criteria of the KDOT Geotechnical Unit is valid.

A great majority of vehicles exiting at this interchange are turning left. In doing so, they appear, from the data collected, to guide to the left of the lane. Because of the large number of left-turning vehicles, as well as a large number of trucks coming from the south that are turning left onto the westbound on-ramp, there are long queues waiting to make left turns. Occasionally, right turning vehicles crowded the right side of the lane to get around the vehicles waiting to make a left turn. Due to positioning of the vehicles at the right-most side of the ramp, additional left-turning vehicles coming down the ramp will move farther to the left. This makes the ramp operate as a two lane ramp, which could increase the incidence of crashes. Additionally, it was observed that when there was a left turning truck waiting to turn, a right turning vehicle had to pull out beyond the front of the left turning truck to observe oncoming traffic. This situation was probably not caused by the location of the longitudinal joint but by the wide paved right shoulder.

4.5 Other Locations

4.5.1 21st & Fairlawn Rd

Driving patterns were observed at several other locations that were identified as having longitudinal joints that might cause confusion to drivers. The southbound leg of the intersection of Fairlawn Rd. at 21st Street in Topeka was studied because the joint crosses the outside lane just beyond an entrance to a shopping center. A photograph of the site is shown in Figure 4.19.

Figure 4.19 Photograph of Fairlawn South at 21st Street

A schematic representation of the southbound lanes at this site is shown in Figure 4.20. If the lateral position of the vehicles is assumed to be guided by the pavement markings, the drivers could position their vehicles along the sections AC and BD, representing inner and outer lanes of the road. The solid double-line represents the centerline of the street and the dashed line represents the paint between the two southbound lanes. The two thin solid lines that continue straight through the diagram represent the joints. The lines connecting the letters are the possible vehicle paths that could be taken as vehicles pass through the area.

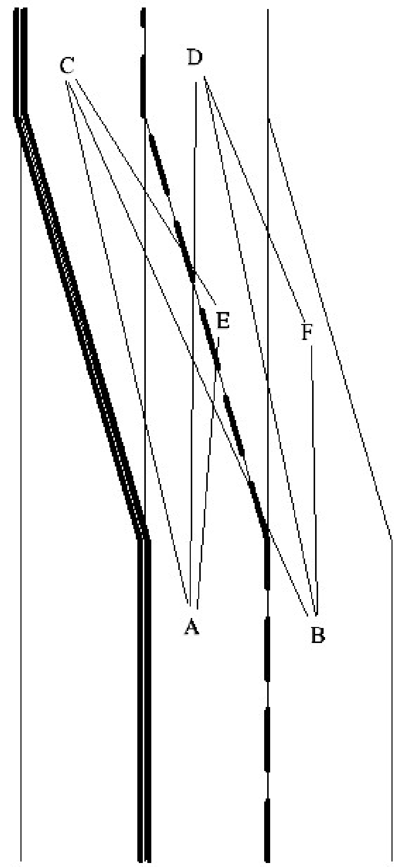

Figure 4.20: Schematic of Possible Movements on Fairlawn South at 21st Street

The paths taken by vehicles were observed and manually recorded. The data was collected in intervals of five minutes for about one hour and fifteen minutes. The movements of vehicles along the various paths AC, AD, AEC, BC, BD and BFD were recorded. 483 vehicles were traveling in these two lanes of the road. Of the 286 vehicles that were in the inside lane at the beginning of the observed section, 242 (85%) followed the pavement makings and remained in the inside lane. There were 24 (8%)

that continued straight and therefore changed lanes. There is no way to know if that was because of the location of the joint or because they had a reason to change lanes. Of greater concern were the 20 vehicles that continued straight and entered the outside lane and then moved back to the inside lane. However, during the observation period, there were no “close calls” between these 20 vehicles and those occupying the outside lane.

Table 4.6: Details of vehicles observed at Fairlawn South at 21st Street

S.No	Section	Number of vehicles	Percentage of vehicles (%)
1.	AC	242	85
2.	AD	24	8
3.	AEC	20	7
	Inside Lane Total	286	100
4.	BD	197	100
5.	BFD	0	0
	Outside Lane Total	197	100

From the values reported in Table 4.6, it can be inferred that approximately, seven percent of the total vehicles observed at this location may be influenced by the joints and by the short distance which the drivers have to move to the left.

4.5.2 21st & I-470, Topeka

The following USGS aerial photograph (Figure 4.21) shows the large amount of joint sealant in both the transverse and longitudinal joints at this location. As can be seen from the location of the joints, the westbound outside lane near the right side of the photograph continues as the exit lane that turns right onto northbound I-470. The westbound traffic was observed for one hour and no problems were observed. However, while driving in the outside lane, the researcher observed a vehicle directly in front move into the exit, without signaling. When the front vehicle reached the end of the exit lane, he or she suddenly swerved back into the outside through lane, nearly clipping the researcher's vehicle. The license plate on the swerving vehicle was from out-of-state, leading the researcher to assume that the driver was not familiar with the configuration of this intersection.

Figure 4.21: WB 21st Street to NB I-470, Topeka, KS

The picture below (Figure 4.22) shows the eastbound off-ramp from I-70 to Wanamaker. As can be seen from the tire rubber that has been deposited on the pavement, very few vehicles travel beyond the joint on the outside of the curve. While this picture does not prove that the driver's path was influenced by the location of the longitudinal joint, it does support the recommendation that the joint should be placed on the outside of a curved ramp, if at all possible, to minimize joint deterioration.

Figure 4.22: East bound off-ramp, I-70 & Wanamaker, Topeka

The next picture (Figure 4.23) is the eastbound entrance on-ramp at the same interchange. Because of its geometry, ramp first curves to the left and then to the right, making it impractical to put the joint on the outside of the curve. The tire marks on the pavement indicates little if any use to the outside of the outside joint. However, it was observed that most vehicles put their right-side wheels on or near the right-hand stripe and joint. This was especially true for combination vehicles.

Figure 4.23: Eastbound on-ramp, I-70 & Wanamaker, Topeka

4.5.3 Wanamaker, North of 21st Street, Topeka

There is a two-lane left turn approach from southbound to eastbound at the 21st and Wanamaker intersection. The approach widens to accommodate the 2nd lane approximately 300 feet north of the intersection. It is indicated on Fig. 4.24 by two white arrows. The joints through the transition continue straight into the intersection. The approach was widened at the beginning of the transition, making a new outside through lane. The outside lane north of the transition becomes the inside through lane and the inside lane becomes the outside left-turn lane.

Figure 4.24: Wanamaker, North of 21st Street, Topeka

It was observed that most of the left-turning vehicles continued straight within the longitudinal joint to the inside lane to make a left turn and later moved another lane to the inside turning lane if desired. This location was observed during an off-peak period and during heavy traffic during the Christmas shopping period, when a larger number of drivers might be unfamiliar with the features of this intersection. At no time did the research team witness any confusion on the part of drivers in the traffic stream.

4.5.4 Ramp between Topeka Blvd & I-470

This location is included in this report, not because of mismatched longitudinal joints, but to show the effects of heavy loads on longitudinal joints. This location is essentially a weaving section for right turning traffic from Southbound Topeka Blvd to the Kansas Turnpike and left turning traffic from Northbound Topeka Blvd and I-470. The weaving traffic must cross the longitudinal joint that is located between the lanes. Figure 4.25, below, shows that there is considerable deterioration in the joint. Although the deterioration may not be entirely attributed to the loads on the joints, it is the author's judgment, that the loads on the joints accelerated the wear that can be observed.

Figure 4.25: Ramp to I-470 & KTA at S Topeka Blvd

CHAPTER 5 - SUMMARY AND CONCLUSIONS

The genesis of this research occurred when KDOT's Bureau of Design became concerned about the potential negative consequences of placing the longitudinal construction joints on the ramps of I-35 at US-75 in the center of the ramp. This would allow the ramp to be placed in one pass of the paving machine. The research staff's approach was to photograph the locations that had longitudinal joints that did not match the lane markings and measure the deviation of the driver from a normal path. It was assumed that when the driver was uncertain about where to drive, the standard deviation would be greater. Although safety is always a consideration in designing highways, accident data did not identify joints as a contributing factor when accidents did occur and the likelihood of an accident at any location identified for study in this research made these data unreliable.

It soon became apparent that the locations that were identified by KDOT and the research staff were all different and would not lend themselves to the analysis approach that was initially conceived. Therefore, the method of analysis varied from a detailed statistical analysis of a large number of vehicles at one location, observations of vehicle operations, and observations of rubber accumulation on the pavement. The locations varied from a curved four-lane street to approaches, intersections, and ramps. Comments were also collected in a survey from KDOT, city and county engineers as well as AASHTO member state's design personnel. . The most specific comments from KDOT field personnel related to the use of temporary striping. When traffic is carried through construction, it is inevitable that lanes will be shifted to accommodate the various construction phases. This situation was beyond the scope of this research project.

While the analysis and the personal observation of traffic operations did not provide hard evidence that placing joints some place other than the edge of lanes was detrimental to traffic operations, it did appear that there was a chance of driver confusion, leading to congestion and a higher potential for crashes. The analysis of the paths of vehicles in the outside west-bound lane of K-18 (Ft. Riley Blvd) in Manhattan indicated that there was a significant number of vehicles that drifted into the inside lane. While no crashes occurred, the potential was greater for incidents to occur.

As a result of the recommendations of KDOT's Geotechnical Unit, special attention was given to the condition of the longitudinal joints at various locations where heavy loads had occurred directly on the joints. While some of them showed little or no wear, it was the judgment of the researchers that most of the joints that had heavy loads directly on them showed greater than normal deterioration. This would support the recommendation of the Geotechnical Unit that, where possible, the joint be placed in such a manner to maintain at least a foot of space between the wheel load and the joints.

In summarizing the specifications of the various states and the comments of persons who were surveyed, most agencies had policies that would discourage mismatched joints and striping. Others commented that is would not be a good idea to allow such an action because of possible driver confusion or operational problems.

It was observed that most of the mismatching occurred where additional turning lanes or medians were added after initial construction. These modifications were added to the existing lanes so that the initial joint configuration was no longer along lane boundaries. Tearing out the initial lanes and totally reconstructing the subject area would be much more costly and disruptive to traffic during construction.

Based on the data collected and the observations made, the researchers recommend that:

1. The agency that is designing and constructing highway projects place the longitudinal joints in such a place as to minimize heavy wheel loads within a foot of the joint.
2. Assure that the joints are continually sealed against the intrusion of water.
3. Assure that the lane striping is highly visible in areas where the longitudinal joints and the lane lines do not match.

APPENDIX A

Table A.1: Specifications of various departments of transportation on the positioning of construction joints with respect to pavement markings

No	State	Specifications
1	Alabama	410.03 h) Joints: Longitudinal joints in the wearing surface shall conform with the edges of proposed traffic lanes, insofar as practical. Any necessary longitudinal joints in underlying layers shall be offset so as to be at least 6 inches {150 mm} from the joint in the next overlying layer. (http://www.dot.state.al.us/NR/rdonlyres/A7030997-448E-4070-AD43-29836F663A97/0/2006_Spec_Book.pdf)
2	Alaska	Standard Specs 401-3.14 Joints: Align the joints in the top layer at the centerline or lane lines. (http://www.dot.state.ak.us/stwddes/dcsspecs/assets/pdf/hwyspecs/english/2004sshc.pdf)
3	Arizona	No information was available on the mismatched joints and pavement markings (http://www.azdot.gov/highways/cns/index.asp)
4	Arkansas	418.06 Construction Methods g) Workmanship: Longitudinal joints shall be placed at lane lines. (http://www.arkansashighways.com/Construc/SpecBK03/03-400.pdf)
5	California	37-2.06 Placing: Longitudinal joints shall correspond with the edges of existing traffic lanes. Other patterns of longitudinal joints may be permitted, if the patterns will not adversely affect the quality of the finished product, as determined by the engineer (http://www.dot.ca.gov/hq/esc/oe/specifications/std_specs/2006_StdSpecs/2006_StdSpecs.pdf#xml=http://dap1.dot.ca.gov/cgi-bin/texis/webinator/search/pdfhi.txt?query=Standard+Specifications+for+road+and+bridge+construction&db=db&pr=www&prox=page&rorder=500&rprox=500&rdfreq=500&rwfreq=500&rlead=500&sufs=0&order=r&cq=&id=45f22839c)
6	Colorado	401.16 Spreading and Finishing: The joints in the top layer of pavement shall be located as follows unless otherwise approved by the engineer 1) For 2-lane roadways, offset 6 to 12 inches from the center of pavement and from the outside edge of travel lanes. 2) For roadways of more than 2 lanes, offset 6 to 12 inches from lane lines and outside edge of travel lanes. Longitudinal joints shall not cross the centerline, lane line, or edge line unless approved by the Engineer. (http://www.dot.state.co.us/DesignSupport/Construction/2005SpecsBook/2005Book/2005SpecBookWhole.pdf)
7	Connecticut	No information was available on the mismatched joints and pavement markings (http://www.ct.gov/dot/cwp/view.asp?a=1385&Q=275956&dotPNavCtr=|41877|#41878)

8	Delaware	748.09 C) 2)Patterns: Longitudinal lines shall be offset at least 2” (50 mm) from the joints and 2” (50 mm) to the inside of the shoulder marks of the pavement (http://www.deldot.gov/static/pubs_forms/manuals/standard_specifications/division_700.shtml#SECTION%20748)
9	Florida	709.4, 713.4 Offset longitudinal lines at least 2 inches from construction joints on portland cement concrete pavement (http://www.dot.state.fl.us/specificationsoffice/2007BK/713.pdf)
10	Georgia	No information was available on the mismatched joints and pavement markings (http://tomcat2.dot.state.ga.us/thesource/specs/index.html)
11	Hawaii	629.03 Do not install pavement markers over longitudinal or transverse joints of pavement surface, pavement making tape and thermoplastic extrusion markings (http://www.hawaii.gov/dot/highways/specs2005/specs/specspdf/629_Print.pdf)
12	Idaho	No information was available on the mismatched joints and pavement markings http://itd.idaho.gov/manuals/Downloads/spec'04'.htm
13	Illinois	No information was available on the mismatched joints and pavement markings http://www.dot.state.il.us/desenv/stdspecs07.html
14	Indiana	503.03 Joints: Longitudinal joints shall be parallel to the centerline The longitudinal joint shall not deviate from the true line shown on the plans by more than ¼th inch (http://www.in.gov/dot/div/contracts/standards/book/sep06/5-2006.pdf)
15	Iowa	No information was available on the mismatched joints and pavement markings (http://www.erl.dot.state.ia.us/OCT_2006/CM/content/8-40.htm#8.43)
16	Kansas	800/2200 Pavement Marking-Painting (d) Alignment: Normally locate longitudinal pavement marking stripes 50 mm. from existing longitudinal joints. (http://www.ksdot.org/burconsmain/specprov/specprov.asp?ID=800)
17	Kentucky	510.03.17 A) Longitudinal Joints: Install longitudinal joints on the centerline or parallel to the centerline within 1/2 inch from the true theoretical position (http://transportation.ky.gov/construction/spec/spec04_pdf.htm) 713.03 Construction: Offset longitudinal joints atleast 2 inches from longitudinal pavement construction joints. (http://transportation.ky.gov/construction/spec/supp.htm)

18	Louisiana	732.03 d) Application of markings: Longitudinal lines shall be offset approximately 2 inches from the longitudinal joints (http://www.dotd.louisiana.gov/highways/project_devel/contractspecs/Part_VII.pdf)
19	Maine	712.05 Application: Longitudinal lines shall be offset at least 50 mm [2 in] from construction joints of portland cement concrete pavement. (http://www.maine.gov/mdot/contractor-consultant-information/ss_standard_specification_2002.php)
20	Maryland	Line and Grade Control (504) Joints in the top layer should be within 6 inches of the lane lines (http://www.sha.state.md.us/businessWithSHA/bizStdsSpecs/ooc/CONMANFNL.PDF)
21	Massachusetts	466.63 Construction Requirements: 1.Application. Longitudinal joints shall be reasonably true to line and parallel to the centerline (http://www.mhd.state.ma.us/downloads/manuals/1995Mspecs.pdf)
22	Michigan	502.03 f) Placing HMA: When placing the uppermost leveling and top course, place the longitudinal joint to coincide with the proposed painted lane lines. (http://mdotwas1.mdot.state.mi.us/public/specbook/)
23	Minnesota	2404.3 General: The location of longitudinal joints shall be subject to the approval of the engineer and shall be located at the edge of traffic lanes (http://www.dot.state.mn.us/tecsup/spec/2005/2401-2481.pdf)
24	Mississippi	401.03.10 Spreading and Finishing: The longitudinal joint in the subsequent lift shall offset that in the underlying lift by approximately six (6) inches. However, the joint in the top lift shall be at the centerline or lane line. (http://www.gomdot.com/business/construction/specs.htm)
25	Missouri	No information was available on the mismatched joints and pavement markings http://www.modot.mo.gov/business/standards_and_specs/highwayspecs.htm
26	Montana	Couldn’t find the exact link to standard specifications
27	Nebraska	424.03 c) Longitudinal markings shall be offset at least 50 mm. from construction joints of portland cement concrete surfaces and joints and shoulder breaks of asphalt surfaces 514.04 Longitudinal joints shall be placed on lane lines where possible. (http://www.dor.state.ne.us/ref-man/specm.htm)

28	Nevada	401.03.12 a) Longitudinal: Place bituminous pavements so that any longitudinal joints constructed are within 300 mm (12 in.) of the final traffic lanes (https://www.nevadadot.com/business/contractor/standards/documents/english-2005sm.pdf)
29	New Hampshire	3.7.1 Joints: Unless and otherwise shown on the plans, the longitudinal wearing course joints shall be at the edge of the lane placed, where the edge line, lane line and centerline pavement markings will be applied, and the joints of other courses shall be offset by approximately 6 in . (150 mm) (http://www.nh.gov/dot/bureaus/highwaydesign/specifications/documents/Division400.pdf)
30	New Jersey	404.17 Spreading and Finishing Longitudinal Joints: LJ in one layer shall offset that in the layer immediately below by approximately 6 inches. However, the joints in the surface course shall be at lane lines (http://www.state.nj.us/transportation/eng/specs/english/EnglishStandardSpecifications.htm)
31	New Mexico	Couldn't find the exact link to standard specifications
32	New York	402-3.09 Carefully plan the placement of the surface course to ensure that the longitudinal joints in the surface course will correspond with the edges of the proposed traffic lanes. (https://www.nysdot.gov/portal/page/portal/main/business-center/engineering/specifications/specs-repository/vol1active1_11_07_0.pdf)
33	North Carolina	No information was available on the mismatched joints and pavement markings http://www.ncdot.org/doh/preconstruct/ps/specifications/dual/Division7.pdf
34	North Dakota	No information was available on the mismatched joints and pavement markings (http://www.dot.nd.gov/dotnet/supplspecs/StandardSpecs.aspx)
35	Ohio	Couldn't find the exact link to standard specifications
36	Oklahoma	411.04 i) Joints: Construct all longitudinal joints within 1 foot from the lane lines. The longitudinal joints in the top layer or in the layer upon which an open-graded friction course is to be placed shall be at lane lines (http://www.okladot.state.ok.us/construction/specbook/specbook-1999.pdf)

37	Oregon	00735.48 : Longitudinal joints: 1) Base Course: Place base course longitudinal joints within 300 mm (12 inches) of the edge of a lane, or within 300 mm (12 inches) of the center of a lane, except in irregular areas, unless otherwise shown 2) Wearing Course: Do not construct longitudinal joints in the wearing course within the area or width of a traffic lane. On median lanes and on shoulder areas, construct joints only at lane lines or at points of change in the transverse slopes, as shown or as directed. (http://www.oregon.gov/ODOT/HWY/SPECS/docs/02book/02_00700.pdf)
38	Pennsylvania	No information was available on the mismatched joints and pavement markings (http://www.dot.state.pa.us/Internet/Bureaus/pdDesign.nsf/ConstructionSpecs408and7?OpenForm)
39	Rhode Island	401.03.11 Joints: Longitudinal joints shall be staggered a minimum of 6 inches and shall be arranged so that the longitudinal joint in the top course being constructed shall be at the location of the line dividing the traffic lanes. (http://www.dot.state.ri.us/engineering/proj/bluebook/CD-Bluebook.pdf)
40	South Carolina	401.32 Longitudinal joints shall be rolled directly behind the paver. The paver shall be so positioned that in spreading, the material overlaps the edge of the lane previously placed by 1 or 2 inches (http://www.scdot.org/doing/const_man.shtml)
41	South Dakota	No information was available on the mismatched joints and pavement markings http://www.sddot.com/operations/specifications/specbook_div2_04.htm
42	Tennessee	Refer 414.07 (http://www.tdot.state.tn.us/construction/specbook/2006_Spec400.pdf)
43	Texas	316.4 G Asphalt placement: Unless otherwise approved, match longitudinal joints with lane lines (ftp://ftp.dot.state.tx.us/pub/txdot-info/des/specs/specbook.pdf)
44	Utah	3.5 Surface Placement Place top course joint within one foot of the centerline or lane line. (http://www.udot.utah.gov/download.php/tid=1101/2005StandardSpecifications.pdf)
45	Vermont	No information was available on the mismatched joints and pavement markings http://www.aot.state.vt.us/conadmin/Documents/2001%20Spec%20Book%20for%20Construction/2001DIV400.pdf

46	Virginia	315.05 However, the joint in the wearing surface shall be at the centerline of the pavement if the roadway comprises two traffic lanes or at lane line if the roadway is more than two lanes in width (http://www.vdot.virginia.gov/business/const/spec-default.asp)
47	Washington	5-02.3 Application of Asphalt: Longitudinal joints will be allowed at only the centerline of the roadway, the center of driving lanes, or the edge of driving lanes (http://www.wsdot.wa.gov/fasc/EngineeringPublications/Manuals/SS2004.PDF)
48	West Virginia	410.10.5 However, the joint in the wearing surface shall be at the centerline of the pavement if the roadway comprises two traffic lanes or at lane line if the roadway is more than two lanes in width (http://www.wvdot.com/engineering/Specifications/2003/Y2KSpecB.pdf http://www.wvdot.com/engineering/Specifications/2003/2K03_SUP.pdf)
49	Wisconsin	415.3.9.1 Joints: Parallel to the centerline along lane edges. On two lane pavements, construct them along the pavement centerline (http://roadwaystandards.dot.wi.gov/standards/stndspec/part4.pdf)
50	Wyoming	409.4.4.1 Ensure that longitudinal joints coincide with the specified locations of lane lines, edge lines and center of traveled ways (http://dot.state.wy.us/Default.jsp?sCode=infsp)

APPENDIX B

SURVEY OF TRANSPORTATION PROFESSIONALS

Longitudinal Construction Joints – Survey Form/AASHTO

As described in the attached memo, we are conducting a study about longitudinal construction joints. Please take a few moments to answer the following questions.

Your contact information:

Name……………………………………………………………………

State……………………………………………………………………

Agency…………………………………………………………………

Position…………………………………………………………………

Phone…………………………….Email…………………………………

Please check the appropriate response.

1. Does your agency allow unmatched joints and pavement markings on public roadways?
   - ☐ Yes
   - ☐ No
2. Are you aware of any locations where pavement markings do not match with longitudinal construction joints?
   - ☐ Yes
   - ☐ No (If you select NO, go to question 6)
3. What are the locations that have unmatched joints and pavement markings? (Check all that apply)
   - ☐ Ramps
   - ☐ Curves
   - ☐ Straight Sections
   - ☐ Channelized Intersections
   - ☐ Others…………………………………………………

4. Have you observed/heard of any operational or safety concerns as a result of unmatched joints and pavement markings?
   - ☐ Operational Problems
   - ☐ Safety Problems
   - ☐ No

   Please explain……………………………………………...

   ………………………………………………………………..……………………………

   ……………………………………….
5. Have you ever overlaid an area or taken some other action to remedy the concerns at such locations?
   - ☐ Yes
   - ☐ No

   If YES, please explain………………………………………..

   …………………………………………………………….………………………………

   ……………………………………….
6. What is your general opinion about unmatched joints and pavement markings?

   ……………………………………………………………………

   ……………………………………………………………………

Thank you for your time.

Please email the completed form to dlandman@ksu.edu **with a copy to** sking@ksdot.org**.**

Longitudinal Construction Joints – Survey Form/KDOT

As described in the attached memo, we are conducting a study about longitudinal construction joints. Please take a few moments to answer the following questions.

Your contact information:

Name………………………………………………………………………

Position…………………………………………………………………

Phone……………………………Email…………………………………

Please check the appropriate response.

1. Are you aware of any locations where pavement markings do not match with longitudinal construction joints?
   - ☐ Yes
   - ☐ No (If you select NO, go to question 6)
2. What are the locations that have unmatched joints and pavement markings? (Check all that apply)
   - ☐ Ramps
   - ☐ Curves
   - ☐ Straight Sections
   - ☐ Channelized Intersections
   - ☐ Others……………………………………………………
3. Please identify these locations.

   1. City……………………….…County………………………

      Street Name………………………………………………..

      Intersection/Ramp………………………………………….

   2. City……………………….…County………………………

      Street Name………………………………….……………….

      Intersection/Ramp………………………………………….

   3. City……………………….…County………………………

      Street Name………………………………….……………….

      Intersection/Ramp………………………………………….

4. Are you aware of more locations in addition to the ones listed in question 3?
   - ☐ Yes
   - ☐ No

5. Have you observed/heard of any operational or safety concerns as a result of unmatched joints and pavement markings?
   - ☐ Operational Problems
   - ☐ Safety Problems
   - ☐ No

   Please explain………………………………………………...
   ………………………………………………………………..……………………………
   ………………………………………
6. Have you ever overlaid an area or taken some other action to remedy the concerns at such locations?
   - ☐ Yes
   - ☐ No

   If YES, please explain………………………………………..
   ………………………………………………………………..……………………………
   ………………………………………
7. What is your general opinion about unmatched joints and pavement markings?
   ……………………………………………………………………
   ……………………………………………………………………
   ……………………………………………………………………
   ……………………………………………………………………
   ……………………………………………………………………

Thank you for your time.

Please email the completed form to dlandman@ksu.edu **with a copy to** sking@ksdot.org**.**

Transportation professionals and engineers from various agencies across the country and in the state of Kansas participated in two-web based surveys conducted through the Kansas Department of Transportation (KDOT). Participants expressed their views on the operational and safety problems that arise in sites having unmatched joints and pavement markings. The general policies of the corresponding agencies were also obtained from the survey. Thirty American Association of State Highway and Transportation Officials (AASHTO) members responded to the first survey. Transportation officials and engineers from different counties in the state of Kansas took part in the second survey. Mixed responses were received on the unmatched joints and pavement markings. Some departments of transportation (DOTs) preferred to match the joints and markings, whereas a few of them were concerned about the maintenance of the pavement and hence were willing to offset the joints from the pavement edge lines. A summary of the survey results from the AASHTO responses are reported in Chapter 3.

APPENDIX C

STATISTICAL ANALYSIS OF THE DATA OBSERVED AT THE FORT RILEY BLVD.

One sample t-test is used to compare the mean of a sample data to a known number. In other words, the mean of a sample is compared to a hypothetical value. For applying the t-test, the data needs to be normally distributed. The statistical analysis software (SAS) can be effectively used for performing the t-test as it directly gives the probability value (*p*-value) which is used in interpreting the validity of either null or alternate hypothesis. The command “PROC TTEST” computes the t-statistic by using the formula,

$$t = \frac{X - \mu}{\left(\frac{s}{\sqrt{n}}\right)} \qquad \text{Equation C.1}$$

where,

t =t-value

X =The mean distance to centerline of vehicles from the right curb of road

μ = Expected position of centerline of vehicles, which is the centerline of the target lane

s =Standard deviation of distance to the centerline of vehicles

n =Number of observations

Initially, the mean distance to the centerline of vehicles computed from the entire dataset is used for performing the t-test by comparing it with a hypothetical value of half of the width of the target lane. The default value of significance ‘α’ used by SAS is 0.05. The SAS software directly gives the probability value, i.e., *p*-value. If the *p*-value associated with the t-test is small ($p<0.05$), there is enough evidence that the mean is different from the hypothesized value. If p>0.05, then the null hypothesis is not rejected and it can be concluded that the mean is not different from the hypothesized value.

For comparing the means of two groups of data, independent group t-test can be applied. In order to apply this test, the data from both the samples should satisfy the criterion of normal distribution. The command “PROC TTEST COCHRAN” can be used in the SAS software to perform the independent group t-test. The command reports two values of t-statistic: one under equal variance assumption and the other under unequal variance. It also reports an *F*-value, which helps to identify the type of t-test used in analyzing the data The *F*-statistic is computed to check the equality of variance, which uses the following formula,

$$F' = \frac{\left(\text{larger of } s_1^2, s_2^2\right)}{\left(\text{smaller of } s_1^2, s_2^2\right)} \qquad \text{Equation C.2}$$

The SAS program displays the *F*-statistic along with a *p*-value. If the *p*-value associated with the *F*-test is greater than 0.05, the null hypothesis that the variances of two samples are equal can be accepted and *t*-statistic is computed by pooled method of equal variance by using the following formula,

$$t = \frac{\left(x_1 - x_2\right)}{\sqrt{s^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \qquad \text{Equation C.3}$$

where,

t =*t*-statistic under the assumption of equal variance

x_1=Mean of the first group

x_2 =Mean of the second group

s^2 =Pooled variance

n_1 =Sample size of the first group

n_2 = Sample size of the second group

The value of pooled variance, s^2,is calculated under the assumption that the population variances for two samples are equal using the following formula:

$$s^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{(n_1 + n_2 - 2)} \qquad \text{Equation C.4}$$

where,

s_1^2 =Sample variance of the first group

s_2^2 =Sample variance of the second group

If the *p*-value associated with the *F*-test is less than 0.05, we reject the null hypothesis and the *t*-statistic is computed under the assumption of unequal variance by using the following formula,

$$t = \frac{(x_1 - x_2)}{\sqrt{w_1 + w_2}} \qquad \text{Equation C.5}$$

where,

t =*t*-statistic under the assumption of unequal variance

x_1 =Mean of the first group

x_2 =Mean of the second group

and where, w_1 and w_2 are computed using

$$w_1 = \frac{s_1^2}{n_1} \qquad \text{Equation C.6}$$

$$w_2 = \frac{s_2^2}{n_2} \qquad \text{Equation C.7}$$

Either the Cochran and Cox approximation or Satterthwaite's approximation is used for computing the t-statistic under the assumption of unequal variance, in which case SAS output reports both values.

The degrees of freedom for Satterthwaite's Approximation is computed as follows:

$$df = \left(\frac{(w_1 + w_2)^2}{\frac{(w_1^2)}{(n_1 - 1)} + \frac{(w_2^2)}{(n_2 - 1)}} \right) \qquad \text{Equation C.8}$$

In summary, if the probability value (*p*-value) for the computed *F* statistic is greater than 0.05, the method of equal variance is accepted. Otherwise, the t-statistic corresponding to Satterthwaite's or the Cochran and Cox approximation is used for analyzing the data.

A histogram was plotted with the cumulative percentage of vehicles on the y-axis and distance to the centerline of the vehicles from the right curb of the road on the x-axis. The best fitted curve represented a bell shape, similar to that of normal distribution. As the data was found to be normally distributed, a t-test was applied for analyzing the data.

Initially, the entire dataset of 14,050 vehicles extracted from the video tapes was analyzed by one sample t-test using SAS software. If the vehicles are assumed to be guided by the pavement markings alone, the expected position of the centerline of the vehicles from the right curb of the road should have been located at 6.2 feet, which is half the width of the target lane, and which is the distance to the centerline of the target lane. The calculated mean and standard deviation of distance to the centerline of the vehicles from the right curb of the road were 7.06 feet, and 1.61 feet, respectively. The null hypothesis has been assumed as the calculated mean distance to the centerline of the vehicles from the right curb of the road is same as half the width of the target lane (6.2 feet). The t-value was calculated using the formula from equation (I), by substituting the values as follows:

$$X = 7.06 \text{ feet}$$

$$\mu = 6.20 \text{ feet}$$

$$s = 1.61 \text{ feet}$$

$$n = 14{,}050$$

The value of the t-statistic was obtained as 63.72. The probability value has been reported in the SAS output as *p*<0.0001. As the *p*-value reported in the output is less than 0.05, with 95% confidence, it can be said that the mean distance to the centerline of the vehicles from the right curb of the road is significantly different from 6.20 feet. It implies that the null hypothesis can be rejected. The *t*-values and *p*-values corresponding to the *t*-tests are reported in Table C.1.

Table C.1: Summary statistics based on type of vehicle at Ft. Riley Blvd.

Description	Sample Size	Mean (feet)	Std. Dev. (feet)	*t*-value	*p*-value (*)
All vehicles	14,050	7.06	1.61	63.72	<0.0001
Passenger cars	5,878	6.36	1.44	8.36	<0.0001
Vans	4,055	7.42	1.49	51.85	<0.0001
Pick-ups	3,352	7.55	1.48	52.92	<0.0001
Heavy vehicles	765	8.50	1.61	39.55	<0.0001

* p<0.05 (significant)

An independent group t-test was carried out to analyze the vehicles traveling under good and bad weather conditions. This test was also applied for vehicles going straight and those taking a right turn. The procedure used for performing the analysis can be explained by considering vehicles traveling under good and bad weather conditions. It has been observed that 8,519 vehicles (n_1) were traveling under good weather conditions, with a mean (x_1) and standard deviation (s_1) of 7.23 feet and 1.71 feet, respectively. It was also observed that 5,531 vehicles (n_2) were traveling under bad weather conditions, with a mean (x_2) of 6.72 feet, and a standard deviation (s_2) of 1.37 feet. The "PROC TTEST COCHRAN" command computes the folded-form *F*-statistic to check the equality of variances using the Equation (II). The *F*-value and corresponding *p*-value were displayed in the SAS output as 1.57 and p<0.0001, respectively. It implies that the method of unequal variance is used for computing the t-statistic.

The *t*-statistic was computed under the assumption of unequal variance by Equation (V) using the values of x_1 and x_2 to be 7.23 feet, and 6.72 feet, respectively. w_1 and w_2 were computed using Equations (VI) and (VII) as 0.000347 and 0.000339. The t-statistic was calculated as 19.62. In addition to this, the "PROC TTEST COCHRAN" also displayed the t-value calculated under the assumption of equal variance by the substituting the corresponding values in Equations (III) and (IV) respectively. However, the t-statistic computed under the assumption of unequal variances has been reported as the test value, as the method of equal variance had been rejected by the *F*-test.

As the *p*-value corresponding to the *t*-test is less than 0.05, the null hypothesis, that the mean distance to the centerline of the vehicles under good weather is the same as that under bad weather can be rejected. Hence, with 95% confidence, it can be said that the mean distance to the centerline of vehicles under good weather conditions is different than that of vehicles under bad weather conditions.

The vehicles were classified into two different categories, vehicles classified on the basis of movement and vehicles traveling under different weather conditions. The summary statistics, i.e., the mean and standard deviation of vehicles traveling under different weather conditions, is reported in Table C.2. In addition to the mean and standard deviation, the *p*-values corresponding to the independent t-tests, along with the *F*-statistic and t-statistic values, are also reported. The t-test has also been applied to the vehicles classified on the basis of movement, and its details are reported in Table C.3. Since the *p*-value corresponding to the *F*- statistic for different vehicles under good and bad weather conditions has been found to be less than 0.0001, the method of unequal variance was used for analyzing the data and hence the t-value calculated using this method is reported as the test value. In terms of the t-test carried out upon classifying the vehicles on the basis of movement, since the *p*-value associated with the *F*-statistic is greater than 0.05, the method of equal variance was used for analyzing the data. Hence, the t-value corresponding to that method is reported as the test value.

All the results were found to be statistically significant, except for the heavy vehicles tested with respect to the movement. The computed *p*-value, corresponding to *t*-test was found to be greater than 0.05 which implies that the result is not statistically significant.

Table C.2: Summary statistics of vehicles under good and bad weather conditions at Ft. Riley Blvd.

Description	Weather Condition	Sample Size	Mean (feet)	Std. Dev. (feet)	*F*-test		*t*-test	
					F value	Pr.>*F*	*t*-value	Pr.>*t*
All vehicles	Bad	5,532	6.76	1.37	1.57	<0.0001	19.62	<0.0001
	Good	8,518	7.27	1.72				
Passenger cars	Bad	2,290	6.10	1.23	1.55	<0.0001	11.70	<0.0001
	Good	3,588	6.52	1.53				
Vans	Bad	1,773	7.10	1.26	1.62	<0.0001	12.47	<0.0001
	Good	2,282	7.66	1.61				
Pick-ups	Bad	1,210	7.21	1.26	1.69	<0.0001	11.09	<0.0001
	Good	2,142	7.75	1.62				
Heavy vehicles	Bad	258	8.13	1.27	1.82	<0.0001	5.47	<0.0001
	Good	507	8.79	1.71				

* p<0.05 (significant)

Table C.2: Summary statistics of vehicles going straight and making a right turn at Ft. Riley Blvd.

Description	Movement	Sample Size	Mean (feet)	Std. Dev. (feet)	*F*-test		*t*-test	
					F value	Pr.>*F*	*t*-value	Pr.>*t*
All vehicles	Right	5,336	6.90	1.61	1.02	0.34	9.40	<0.0001
	Straight	8,714	7.16	1.60				
Passenger cars	Right	2,221	6.14	1.44	1.02	0.52	9.10	<0.0001
	Straight	3,657	6.49	1.42				
Vans	Right	1,503	7.16	1.45	1.07	0.12	6.07	<0.0001
	Straight	2,552	7.47	1.51				
Pick-ups	Right	1,295	7.42	1.46	1.04	0.46	4.21	<0.0001
	Straight	2,057	7.64	1.49				
Heavy vehicles	Right	317	8.58	1.48	1.30	0.01	1.19	0.2455
	Straight	448	8.44	1.69				

* p<0.05 (significant)

APPENDIX D

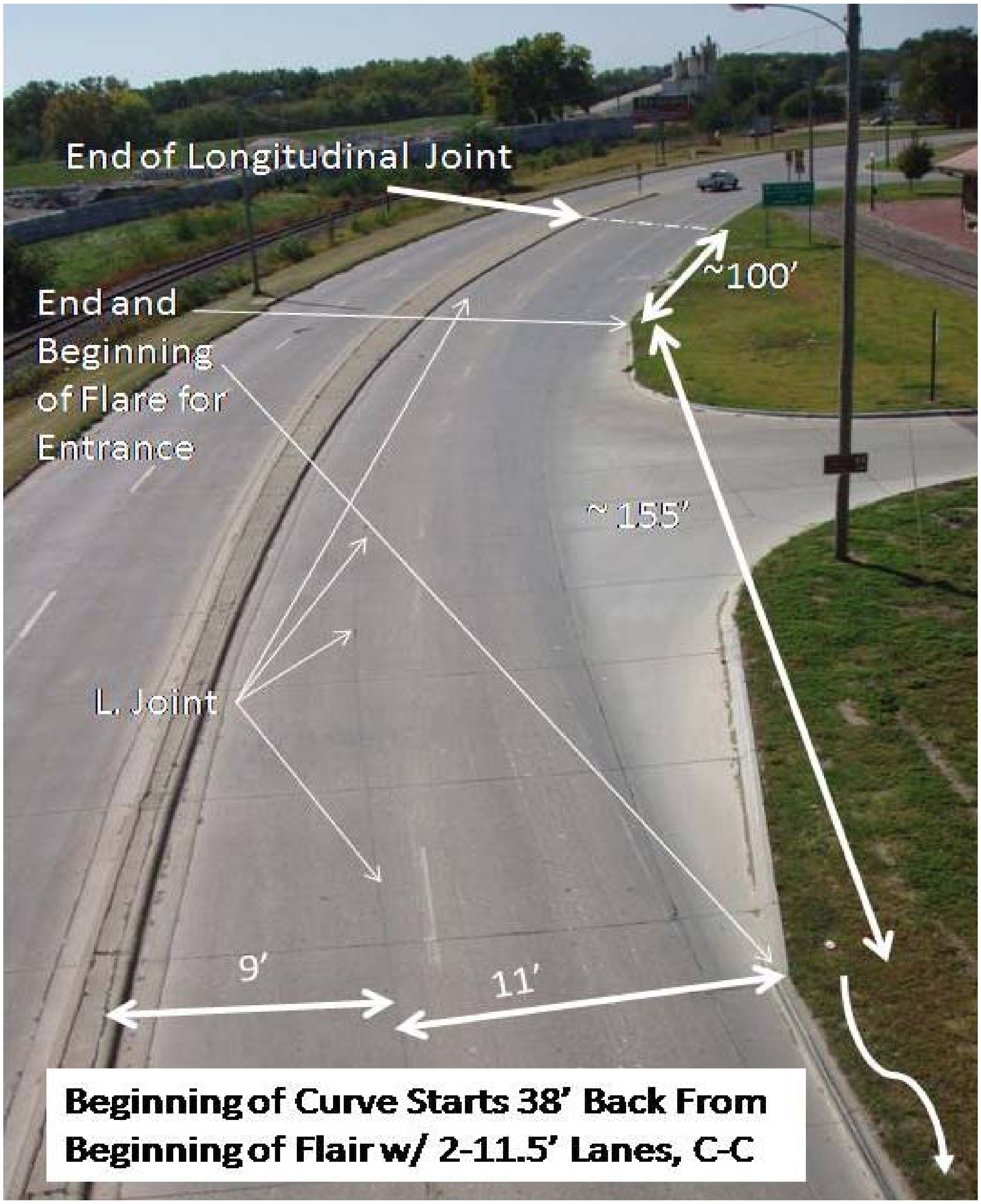

Figure D.1: Dimensions of Key Elements on K-18 (Ft Riley Blvd)

This figure complements Figure 4.4 showing the locations and dimensions for the longitudinal joint that was concurrent to the centerline stripe to near the beginning of the horizontal curve. The distance between the joint and the inside curb gradually decreases until disappearing.

K - TRAN

KANSAS TRANSPORTATION RESEARCH
AND
NEW - DEVELOPMENTS PROGRAM

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:

KANSAS DEPARTMENT OF TRANSPORTATION

THE UNIVERSITY OF KANSAS

KANSAS STATE UNIVERSITY