EFFECTS OF UNMATCHED LONGITUDINAL JOINTS AND PAVEMENT MARKINGS ON THE LATERAL POSITION OF VEHICLES

by

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Abstract

Motorists generally follow the guidance provided by the pavement markings while traveling on roads. Under certain circumstances, construction joints may be necessary in concrete pavements, which are generally designed to be coincident with the pavement markings. At some locations, however, the construction joints may not exactly match the pavement markings. These situations may create confusion in the minds of drivers, which may lead them to follow joints instead of the markings. In the absence of detailed studies on this topic, an effort was made in the present study to evaluate the effects of unmatched longitudinal construction joints and pavement markings on the lateral position of vehicles.

Sites having the characteristics of unmatched longitudinal construction joints and pavement markings were identified, and detailed data were collected at one of the sites. Video camera technique was used for capturing the movements of vehicles along the test site for longer durations. The video tapes were later reduced in the laboratory to extract necessary information. The distance to the right side of the vehicles from right curb of the road, the type of vehicle, presence of vehicles in the adjacent lane, weather and light conditions, and the movement of the vehicles immediately after traversing the section of the road having unmatched longitudinal construction joints and pavement markings were the main parameters observed while reducing the data. Two surveys were also conducted for gathering the opinions of some practitioners and engineers on the issue.

Statistical analyses were carried out using t-tests to evaluate if there were differences. Several comparisons were made for different types of vehicles based on various conditions. The analysis results indicated that there was a statistically significant difference between the actual and expected distances to the center-line of vehicles, implying that the lateral position of vehicles may have been affected by the joints.

A model was also developed to determine the lateral position of the vehicles by considering the parameters used in the analysis. Based on the survey results and analysis of field data, it was found that the lateral position of vehicles may have been affected by the unmatched joints and pavement markings.

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The love and affection of my family members, friends and well-wishers, have been a driving force for me for studying at Kansas State University. I appreciate them for their friendship and support. I am indebted to them.

Dedication

I would like to dedicate my thesis to my late grandparents, Chellamma, and Saroja. I would also dedicate my work to my parents Subhash Babu and Jhansi Rani, my brother Ujwal and my uncle Venkata Ramana. A special person in my life, Madhusudhana Rao changed the way I look at things and perceive them. It is because of him that I was able to complete my Bachelor's degree in engineering and now my Master's. I would also like to dedicate my thesis to him.

CHAPTER 1 - Introduction

1.1 Background

Drivers rely on a complex series of visual cues to safely navigate through the roads. Longitudinal lines, transverse lines, arrows, words, symbol markings and special markings which constitute different types of pavement markings normally guide the motorists in positioning their vehicles on the roads. The center-lines, lane-lines and the edge-lines are marked at the center of the road, lanes of travel and edges of the pavement respectively. These are used to delineate vehicular paths of travel along the roadway. Pavement edge-lines have been observed to have an effect on the vision of drivers, thereby confining the vehicles within a travel lane. In addition to the pavement markings, speed of vehicular traffic, traffic composition, weather and light conditions at the time of travel, roadway geometric design features, physical condition of drivers, and personal attributes may also have an influence on the behavior of the drivers, thus having an effect on the lateral position of vehicles on the roads.

Stresses are induced in concrete pavements due to several factors, prominent being the movement of vehicles. The volume of concrete is affected due to these stresses. Joints allowing the contraction and expansion of concrete, without disturbing the structural integrity of a pavement are known as contraction and expansion joints. In addition to these joints, another type of joints may be used in the pavement to expedite the construction process for separating the paved area into strips necessary for the handling and placing of concrete. They are termed as construction joints. Longitudinal and transverse joints are the two types of construction joints which may be provided in the pavements depending upon their necessity. In situations where a pavement is wider than the paving machine a longitudinal construction joint occurs. If the longitudinal construction joints are provided in the pavements, they are normally expected to coincide with the pavement markings. In some circumstances, however the longitudinal construction joints do not match with the pavement markings. Under these situations, it is important to investigate whether the lateral position of vehicles gets affected by the unmatched longitudinal construction joints and pavement markings.

Studies were conducted by Williamson, Missouri State Highway Department, Hassan, Stevyers, Sun, and Davidse in the past to check the effects of pavement edge-lines on the lateral position of vehicles. It was concluded from the studies that the lateral position of vehicles was affected by the pavement edge-lines. As no research was conducted to verify the effects of unmatched longitudinal construction joints and pavement markings on the lateral position of vehicles, an effort was made in this study to verify the same.

1.2 Problem Statement

Drivers may be affected by the configuration of pavement markings and longitudinal joints on certain roads. Confusion may arise from the unmatched longitudinal construction joints and pavement markings, which may lead the drivers to unwarranted exits, unwanted locations, or even to a dead-end. This study was conducted to verify the problems created due to the unmatched longitudinal construction joints and pavement markings on the lateral position of vehicles.

1.3 Objectives

The primary objective of this study was to evaluate the effects of unmatched longitudinal construction joints and pavement markings on the lateral position of vehicles. Null Hypothesis: The mean distance to the center-line of vehicles is equal to a hypothetical mean value, and its alternative hypothesis: The mean distance to the center-line of vehicles is not equal to a hypothetical mean value were assumed.

A linear regression model was developed as an effort to predict the lateral position of the vehicles from the data collected at one of the locations.

1.4 Outline of the Thesis

This thesis consists of six chapters. Chapter one contains the information on the general details of the project in addition to the objectives of this study. Chapter two includes details on the previous studies conducted in relation to the present research. It also contains a summary of the construction specifications on the joints and markings of all the state departments of transportation. The data collection section is included in Chapter three. The details on the surveys conducted to solicit opinions of various transportation professionals are also included in this chapter. Summary results of two surveys along with the techniques used for data collection are also discussed.

Chapter four contains the methodology for analyzing the data. Basic information on the statistical tests is included in it. Chapter five discusses the results obtained on analyzing the data. It also contains the information on the linear regression model for the data collected at one of the sites. Chapter six contains the information on the findings obtained from this study. The appendices are also included to give a better understanding on certain topics discussed in other chapters of this thesis.

CHAPTER 2 - Literature Review

Studies were conducted in the past to evaluate the effects of the edge-lines on the speed and lateral position of the vehicles. Details regarding the previous studies are included in the section 2.1 of Chapter two. Construction specifications of all the state departments of transportation were studied in order to verify whether a provision regarding the positioning of pavement markings with respect to the joints was available or not. A summary of the specifications along with other details are discussed in the section 2.2 of Chapter two.

2.1 Studies on the Effects of Edge-Lines on Lateral Position of Vehicles

Currently, not much literature is readily available on research conducted in regard to the unmatched construction joints and pavement markings. However, few studies were carried out in the past, where researchers tried to evaluate the effects of pavement edge-lines on the lateral position of vehicles.

A research was conducted by Williamson in Connecticut in 1960 to evaluate the influence of pavement edge markings on operator behavior (*1*). Four sites were chosen as test locations for the study. The officials of the Connecticut Department of Transportation were of the opinion that the painted curbing would furnish drivers with improved pavement delineation during inclement weather or fog conditions. A straight section of the road, a curve (tangent section) and a newly constructed pavement section were chosen. It was possible to augment the effectiveness of pavement markings on a highway with variances in roadway width and cross slope as different types of roads was selected. The parameters measured along the test sites were the lateral position and speed. Chalk lines were placed in the transverse direction along the sections of the road, and the shift in position of the left wheels of the vehicles was observed after the painting of edge-lines. A reduction in the speed of vehicles was also observed on the roads painted along their edges. It was observed that the application of a painted line along the outer edge of the pavement affected the lateral position of the vehicles. It was also discovered that the most significant change in position occurred during darkness.

Another study was conducted by the Missouri State Highway Department in 1969 to determine some of the effects of the edge-line striping on the behavior of the drivers (*2*). It was accomplished through the analysis of the lateral vehicular placement, vehicular speeds and driver comfort. These parameters were measured before and after placing the edge-lines on rural, 2-way highways having varying traffic volumes, surface types, and roadway widths. Vehicular placement was measured through the use of an electronic placement tape which was connected to a 20-pen graphic recorder on the roads of widths between twenty ft. and twenty four ft. The tape was positioned along the test section in such a way that the placement measurements were made in the lane of interest and opposing or passing vehicles were recorded in the other lane. Switches were located in the intervals of one-foot across the entire length of the tape. As the vehicles crossed the tape, different combination of switches were activated, depending on the lateral position of the vehicles. The classification of the vehicles as car or truck in the lane of interest was recorded manually as soon as they crossed the placement tape. From the analysis of the study results, the researchers found that, after applying the edge-lines, the vehicles tend to move closer to the center-line under free-flow condition.

In 1970, another study was carried out by Hassan to evaluate the effect of edge-line marking on narrow rural roads (*3*). Two road sections of widths 18 ft. and 24 ft. were selected for this study conducted in Maryland. One mile sections of the two roads were chosen, separated by two solid lines, which also included a no-passing zone. Land use patterns for these road sections was different i.e. it varied from residential to agricultural. The variables considered while measuring the speed and lateral placement of vehicles were the edge marking treatment, roadway alignment, light-condition and direction of travel. The observations were recorded before and after the application of edge markings, along a tangential and a curved section, and also under daylight and nighttime conditions. Type of the vehicles such as passenger cars and trucks were also observed. For collecting the data, traffic counters of various lengths were placed across the width of the roadway. The data corresponding to the average distance from the center-line to the nearest edge of the vehicles was obtained from this setup. Placement of vehicles was measured within three inches. Similar procedure was adopted for collecting the data of the vehicles after applying the edge-lines. The results were interpreted and it was concluded that there was a significant impact of the pavement edge-line on the lateral position of vehicles. The vehicles were positioned closer to the center-line of the roadway on the application of the pavement edge-lines. Statistically significant results were observed for the data of the vehicles collected at nighttime, when compared with the daytime observations.

Experiments were carried out on four rural roads in the northern part of the Netherlands by Steyvers, et al (*4*). As per Dutch regulations, two roads of the four were control sites: one had no lines (of road width 13.6 ft.) and the other had only a dashed axis line (of road width 14.8 ft. having 2 lanes each of 7.2 ft.). The other two roads were adapted as experimental roads: one with continuous edge-lines (of road width 14.6 ft. and lane width 13.2ft.), the other with dashed edge-lines (of road width 14.8 ft. and lane width 13.2ft.). All lines were of 10 cm. in width. The dashed axis line had dashes with a length of 3 m and an interval of 9 m. The dashed edge-line having dashes of 3 m and intervals of 1m were used. In June 1995, video recordings were carried out on all the roads, for a time period of eight hours, from 7 A.M. to 3 P.M. The video equipment was hidden in a mini-refuse container, positioned alongside the road, which could not be recognized as such, as they were very common in the Netherlands. Before starting the activity of recording, the road was marked enabling calibration before analysis. Video images were analyzed by displaying the tape on a computer screen and marking the position of the wheels of passing vehicles. Only the vehicles closer to the video camera were analyzed as there was asymmetry. In addition to the measurement of lateral position of vehicles, other parameters such as driving speed and mental effort were also assessed. From the experimental results, it was observed that the vehicles on edge-lined roads drive more towards the center of the road, than vehicles on the axis-lined roads. The results were more apparent in the darkness. From the results, it was concluded that for narrow rural roadways with pavements widths between 13.5 ft. and 14.8 ft. there is a significant effect of the pavement edge-lines on the lateral position of vehicles, shifting the vehicles more towards the center of the road.

Sun et al. performed a study in Louisiana to evaluate the effects of pavement edge-lines on lateral position of vehicles (*5*). Air switch devices (also known as road tubes) were used for collecting large number of data samples, as these were found to be more reliable, less intrusive, and easier to setup in the field. Three traffic counters, each connected with at least two tubes were used for collecting the data. The data for vehicles with their right tires touching the one ft. section of roadway, next to the pavement edge, and between one and two ft. from the roadway section, number of vehicles crossing the center-line, hourly volume, and operating speed of vehicles were obtained. Data were collected at a total of ten sites on rural two-lane highways of

Louisiana for at least twenty four hours before and after implementation of edge-lines. With the implementation of edge-lines, it was found that the vehicles followed a more centralized path which indicated that the lateral position of vehicles was affected by them.

The effects of edge-lines on three important parameters, speed, lateral position and human perception were the basis of a study conducted in Tyler, Texas (*6*). Driver behavioral measurements were collected as a surrogate measure of safety. As per this criterion, safety was defined as the absence of systematic potentially dangerous driver actions. Stationary observations design, test driving and laboratory experiments were the approaches selected to evaluate the effects of edge-lines on the behavior of the drivers. A well-positioned video camera was used for obtaining the data pertaining to the vehicles traveling on the selected road sections. The data was collected on three rural highways each of lengths 9 ft. 10 ft. and 11 ft. respectively. Fiducial marks on the pavement surface were used in the data collection process, in both daylight and darkness. Observations were collected on all three test sections without the presence of the edge-lines. Video recording was carried out along the three test sections after striping.

The videos were later reduced for obtaining the data corresponding to speed and lateral position of the vehicles. The dynamic driver responses to the edge-lines were examined by the test driving method. Digital instruments were used for measuring speed of the vehicles in intervals of 0.1 sec. The distance between the two marks along the windshield was measured in terms of pixels, and later converted into centimeters. The distance from the vehicle driver side front wheel to the center-line of the vehicle i.e. the lateral position of the vehicle was obtained by using this method. In addition to the test driving method, laboratory experiments were also carried out for observing the speed and lateral position of vehicles. It was found that on the implementation of edge-lines along the roadways, and also for increasing lane widths, the drivers were found to move closer to the center-line of the road under all lighting conditions. It was further concluded that the lateral position of vehicles seems to be affected by the pavement edge-lines.

Davidse et al performed a meta-analysis of the studies which were conducted to evaluate the effects of an edge-line on speed and lateral position of motorized road users (*7*). Meta-analysis was described as a secondary analysis of the study results. From the study, it was observed that a shift in the lateral position of the vehicles towards the edge of the road depends on the width of the shoulders. It was also found that, adding an edge-line to a road with trees or buildings next to it had the same effect. From the meta-analysis, the authors concluded that there is an effect of the edge-lines on the lateral position of the vehicles.

Several methods were used by researchers in the last few decades for collecting field data. The parameter that was measured in all the studies was the lateral position of vehicles. Upon considering all the methods, video recording was found appropriate for collecting data at the location of the test site. The video recording equipment was setup at the site and data was collected as per the requirements of the study.

2.2 Details on Construction Specifications of Various Transportation Agencies

Extensive research was carried out in the last few decades to evaluate the effects of pavement edge-lines on lateral position of vehicles, but no study was conducted to assess the effects of unmatched pavement markings and longitudinal construction joints on the lateral position of vehicles. The construction specifications of various departments of transportation were studied to check for a provision concerning the matching of joints with pavement markings. A summary of the specifications of the transportation agencies on the positioning of the joints with respect to the markings are included in Table 2-1. More information regarding the construction specifications pertaining to the positioning of the joints with respect to the pavement markings is provided in Appendix A.

Table 2-1 Summary of Specifications of Various Departments of Transportation on Unmatched Joints and Markings

Details of various departments of transportation	Number of States
Construction specifications on positioning of joints with respect to markings Requiring the joints to be concurrent either with center-line or edge-line (21) Preferring to match the joints only with the edge-line of a travel lane (14)	35
No guidelines regarding the placement of joints with respect to markings	12
Construction specifications could not be obtained	3
Total number of departments of transportation	50

The review of construction specifications of various departments of transportation indicated that the states of Alaska, Colorado, Delaware, Florida, Hawaii, Indiana, Kansas, Kentucky, Louisiana, Maine, Massachusetts, Mississippi, New Hampshire, Rhode Island, Utah, Virginia, Washington, West Virginia, Wisconsin and Wyoming preferred to match the joints either with the center-lines or edge-lines of a travel lane.

The construction specifications of the departments of transportation of Alabama, Arkansas, California, Maryland, Michigan, Minnesota, Nebraska, Nevada, New Jersey, New York, Oklahoma, Oregon, South Carolina, Tennessee and Texas had more strict guidelines on the positioning of construction joints with respect to the pavement markings. Those agencies preferred to position the joints in concurrence with the edges of the travel lane.

No provision on the placement of joints with respect to pavement markings were specified in the construction specifications of the departments of transportation of the states of Arizona, Connecticut, Georgia, Idaho, Illinois, Iowa, Missouri, North Carolina, North Dakota, Pennsylvania, South Dakota and Vermont. The specifications of the states of Montana, New Mexico and Ohio were not possible to be obtained.

CHAPTER 3 - Data Collection

The data collection section is divided into two categories: survey of transportation professionals and field studies. The methods of conducting these surveys, summary of the surveys, and data collection techniques are explained in detail in sections 3.1 and 3.2 of Chapter three.

3.1 Survey of Transportation Professionals

Surveys were conducted to gather information from transportation professionals and engineers on unmatched longitudinal construction joints and pavement markings. The other objective of the surveys was to identify the sites having the characteristics mentioned. In this regard, two questionnaires were developed, which were intended for use by the members of the American Association for State Highway and Transportation Officials (AASHTO) and the Kansas Department of Transportation (KDOT). Officials were asked to respond to a set of questions as a part of the web-based online survey. The sample questionnaires are included in the Appendix B. A summary of the survey results responded by the members of AASHTO is provided in Table 3-1.

Table 3-1 Summary of the Survey Results of the Responses from the Members of AASHTO

State	Operational/Safety problems due to the unmatched joints and pavement markings	General policy of the transportation agency on the unmatched joints and pavement markings
Alabama	Longitudinal joint (LJ) was presumed to be the weakest area of the lane. If the joints were within the lane, the members believed that operational problems would arise. If wheel path ran along that LJ, the members opined that a failure may occur.	The agency thought that it was not a better practice to have unmatched joints and pavement markings. The specifications stated that 'LJ's in the wearing layer shall confirm with the edges of the proposed traffic lane, in so far as practical.

Arizona	Safety concerns were expressed by one of the four regional traffic engineers and one maintenance engineer. They were concerned about the location of joint in the wheel path.	Various opinions were expressed based on the type of the pavement. Neither operational nor safety concerns were reported for the asphalt or doweled concrete pavements. It was found that for un-dowelled concrete, there were issues concerning the vertical misalignment.
Arkansas	Neither operational nor safety problems were reported to the DOT.	No problems were reported due to the unmatched joints and pavement markings when then pavement was built correctly. Unmatched joints and pavement markings are tried to be avoided.
Colorado	Neither operational nor safety problems were reported to the DOT.	No problems were reported if the joints were within one foot from the pavement marking. No adverse traffic problems were reported for the 14 ft. driving lanes, having pavement markings placed at 12 ft.
Connecticut	It was felt that operational and safety problems would arise from those situations.	An offset of 6 inches is allowed for the joint from the markings as they wished to avoid the failure of either of them due to the failure of the other.
Delaware	It was expressed that operational problems would arise if the longitudinal joint is in the wheel path.	Joints and markings are tried to be matched so as to eliminate the joints within the wheel paths. It was observed that premature failure and raveling of joints occurred when the wheel path was at the longitudinal joint.
Florida	Neither operational nor safety problems were reported to the DOT.	It was felt that joints in the wheel path may create performance issues.

Georgia	It was felt that operational and safety problems would arise from the unmatched joints and markings. It was assumed that the drivers perceive the joints as markings when the markings get faded.	On ramps and intersections, the unmatched joints and markings were acceptable. Satisfactory results were not obtained in couple of areas where it was allowed. Hence, it was not preferred to use the unmatched joints and markings within the interstate travel lanes or lane shifts.
Iowa	It was felt that operational and safety problems would arise from those situations.	It was felt that it was not a good practice.
Kentucky	No comments were made on this issue.	No comments were made on this issue.
Louisiana	It was found that operational problems would arise from those situations. Lateral movement of vehicles was observed along the section of roads when markings were faded.	Operational effects of not aligning the joints and pavement markings were found to be minimized by reconstruction of portions of the road for breaking up the construction joints.
Maine	It was felt that operational and safety problems would arise from those situations.	Unmatched joints and pavement markings are not acceptable as per their specifications.
Maryland	It was felt that safety problems would arise from those situations.	Were not aware of a significant problem due to the mismatched joints and markings.
Michigan	It was felt that the drivers would be confused due to the mismatch, thereby creating some operational and safety problems.	As per their standards, it was found that they required matching the joint lines with the markings allowing rare exceptions.

Mississippi	Neither operational nor safety problems were reported to the DOT.	In most of the situations, it was found that markings were much more visible than the joints and never caused problems. It was preferred to offset the joints from the markings for better appearance.
Nebraska	Neither operational nor safety problems were reported to the DOT.	It was not desirable to have mismatched joints and pavement markings.
Nevada	It was felt that operational and safety problems would arise from those situations. Under rainy conditions and on wet pavements, it was found that the drivers followed the joints, perceiving them as edge-lines.	Unmatched joints and pavement markings was not allowed by the agency.
New Hampshire	It was felt that operational and safety problems would arise from those situations, which may cause failure in the pavement.	It was not a good idea to provide unmatched longitudinal construction joints and pavement markings.
New Jersey	Neither operational nor safety problems were reported to the DOT.	It was preferred to offset the pavement joints from the traffic stripes by 6 inches.
New York	It was felt that operational and safety problems would arise from those situations.	It was preferred to keep the joints and markings together. It was wished to position them in the middle under unavoidable circumstances.
North Dakota	It was felt that operational and safety problems would arise due to the mismatch. It was found that there was a possibility of side-swipe crashes in the areas of mismatch by the results obtained from crash analysis.	The mismatch was believed to create safety problems.

Pennsylvania	It was felt that operational and safety problems would arise due to the mismatch. The accidents reported in those locations were attributed to the confusion in lane assignments.	It was preferred to avoid unmatched joints and markings at all costs.
South Carolina	Neither operational nor safety problems were reported to the DOT.	It was preferred to match joints and markings.
Tennessee	Neither operational nor safety problems were reported to the DOT.	No comments were exactly made regarding the mismatch.
Texas	Neither operational nor safety problems were reported to the DOT.	It was opined that the placement of markings over the joints was detrimental to the durability of the markings.
Virginia	It was found to have safety concerns regarding the motorcycles traversing the joints. It was felt that appropriate signs would alert the motorists of a possible safety hazard.	It was preferred to locate the joints at the end of the travel lanes for concrete pavements. They wished to locate the joints at the center of the travel lane for asphalt pavements.
West Virginia	It was felt that operational and safety problems would arise due to the mismatch, especially under rainy conditions.	They commented that they would not want to allow the situation of a mismatch between joints and markings to happen if at all possible.
Wisconsin	It was felt that operational and safety problems would arise during nights and under rainy conditions.	It was preferred to offset the joints from markings by at least 3 to 4 inches as they were considered about the maintenance.

Several agencies were concerned about the operational and safety problems that may arise due to the unmatched joints and pavement markings. The agencies were of the opinion that periodical maintenance of the pavement markings by keeping them fresh could mitigate the problems caused due to mismatch.

The second survey involving transportation engineers and other officials within Kansas was mainly targeted to gather the local opinions to identify suitable sites. Eighteen responses were received for this survey conducted within the state of Kansas. Out of the eighteen responses received, fourteen officials of various regions were of an opinion that the unmatched longitudinal joints and pavement markings may create problems. Four officials were not aware of the sites having unmatched joints and pavement markings, and hence did not comment on the issue. A summary of responses received from the survey participated by the city and county engineers within Kansas is provided in Table 3-2.

Table 3-2 Summary of the Survey Results of the City and County Engineers within Kansas

Area / Region	Operational/Safety problems due to the unmatched joints and pavement markings.	General opinion of the engineer/official on the unmatched joints and pavement markings.
Atwood, Rawlins	Has not commented on the issue.	On curves and joints the engineer preferred to match joints and markings. Was of the opinion that on deterioration of the markings, motorists use joints instead of markings.
Ellis	Was of the opinion that there may not be any safety problems due to the mismatched.	Did not have any opinion on this issue.
Hays	Has not commented on the issue.	Under conditions which are lesser than the optimal weather conditions and under dusk/dawn conditions, was of the opinion that motorists would generally follow the joints.
Hutchinson / Reno	It was felt that safety problems may arise from these situations.	Thought that it was a bad idea. Since the traffic volume on their roads was very low, they did not have accident history to demonstrate.

Kansas City Metro Area	Operational and safety problems were caused due to the mismatch. Several complaints were received by the agencies as several accidents occurred due to the reason that the marked lanes were not following the joints.	It was believed that the lane-lines not following the longitudinal joints are a disaster and should be avoided.
Kansas City / Wyandotte County	It was felt that safety problems arise due to mismatch. Complaints were heard from drivers about being confused due to the joints leading them to an unintended turn or lane.	Was of the opinion that the potential hazardous or confusing situations may arise when the drivers travel under high speeds, inclement weather or if the drivers are inattentive. It was suggested not to alter the KDOT's policy.
Leawood	Has not commented on the issue.	It was preferred to match joints and lane-lines
Olathe	Has not commented on the issue.	It was not an issue as long as the joint was in good condition. It was felt that problems would arise if the joint starts degrading and becoming more visible.
Osage City	Have not encountered any adverse conditions.	Has not commented on the issue.
Ottawa	It was felt that operational and safety problems would arise due to the mismatch. It was also felt that it was a dangerous practice as it would cause the driver to deviate from the correct lane, especially under inclement weather conditions.	It was felt to be a dangerous practice and was preferred to be avoided.

Overland Park	Has not commented on the issue.	It was not thought to create unsafe conditions for driving.
Saline County	It was felt that operational and safety problems would arise when the pavement lines fade off, creating confusion among the drivers that the joint is also a lane-line.	It was responded as a bad idea.
Wamego	Has not commented on the issue.	It was responded that it would be difficult to stay in the lane if the drivers look at the black marking (joint) while traveling.
Wichita Sedgwick	Has not commented on the issue.	It was not concerned as a problem as long as a noticeable pavement marking was maintained.

The engineers and officials who responded to the survey were of the view that operational and safety problems may arise due to the mismatched joints and pavement markings. Under the condition of faded pavement markings, joints may become strikingly visible and also create problems. They also expressed that during inclement weather conditions, the unmatched joints and markings may create safety problems. Some of them suggested that as long as discernible pavement markings are maintained, they had no issues concerning the mismatch.

3.2 Field Studies

The necessary inputs for investigating the sites which had prominently visible longitudinal joints were obtained from the second survey which had the opinions of local engineers on certain issues regarding the unmatched longitudinal joints and pavement markings. Upon identifying the sites which had non-coincident joints and markings, field studies were conducted for collecting the data at various locations. Detailed data were collected only at one of the sites, at Fort Riley Boulevard, Manhattan, Kansas, whose details are discussed in the subsection 3.2.1 of Chapter three. The details on other locations, MacVicar Avenue and K-

4/KTA Interchange, and I-35/US-75 Interchange, in Topeka, Kansas, are discussed in subsection 3.2.2 of Chapter three.

3.2.1 Data Collection at Fort Riley Boulevard

Figure 3-1 is an aerial image of the test site at Fort Riley Boulevard. Figure 3-2 is a photograph of the test site.

Figure 3-1 Aerial Image of the Test Site at Fort Riley Boulevard, Manhattan, Kansas

The test site at Ft Riley Blvd. is a four-lane road, with two lanes in each direction, which is shown in Figure 3-2. A new lane was added to the westbound section of the road, which was built at the middle of the right-lane. It was provided as an access to the rail road station located in the vicinity of the test site. The road continued towards the southbound of K-18, the ramp exiting the bridge. This location was primarily chosen because a mismatch between the longitudinal construction joints and pavement markings was observed. It was selected to verify whether the mismatch had an influence on the lateral position of the vehicles. The lane configuration and the condition of the pavement markings are shown in Figure 3-2.

Figure 3-2 Test Site at Fort Riley Boulevard, Manhattan, Kansas

Data was collected at the test site at Ft. Riley Blvd. in two different stages. The first stage of video recording was carried out when the pavement markings were obliterated i.e. the data was collected under faded pavement markings. Data was also collected at the test site at Ft. Riley Blvd., to perform a before-after study, which was recorded in its second stage. Methods of recording data, and of video recording equipment used for data collection are discussed in following paragraphs.

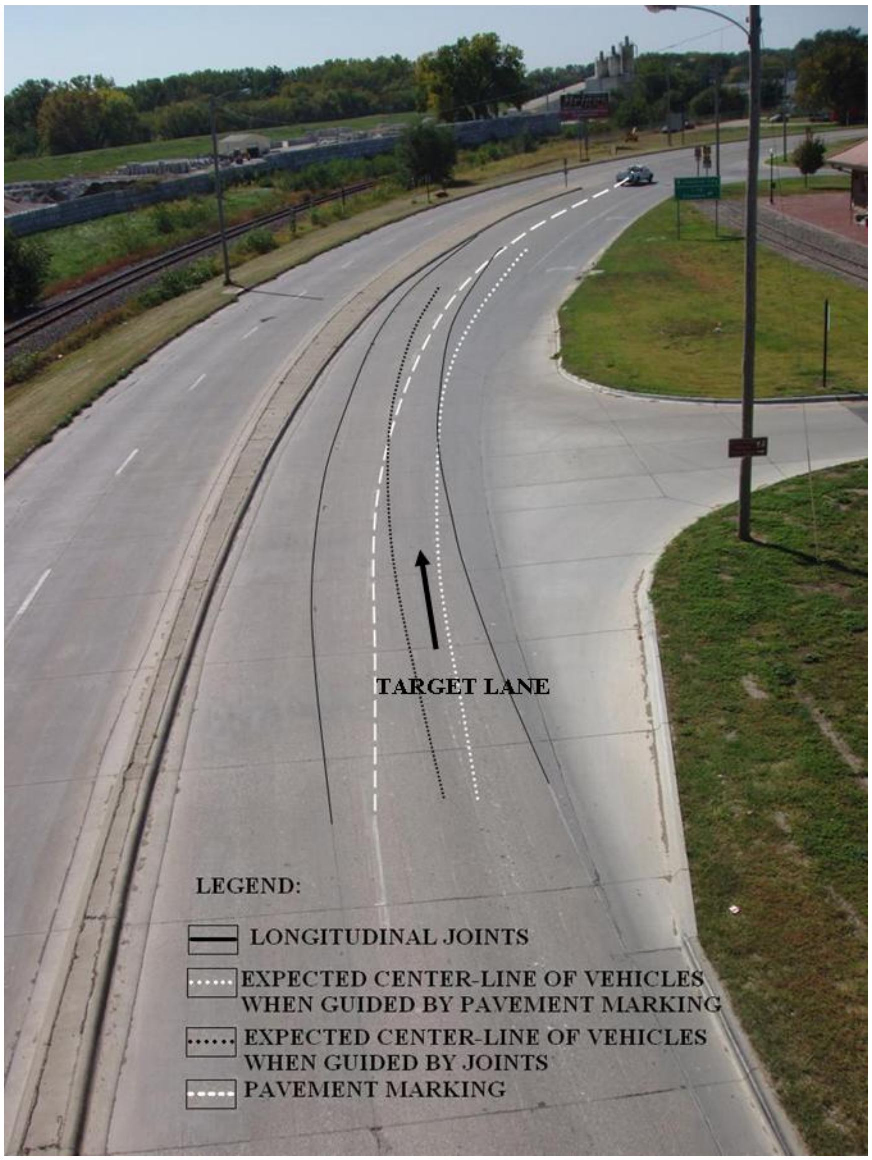
The first stage of recording the observations at the test site at Fort Riley Boulevard was carried out by a video camera with a fish-eye lens, setup on a utility pole which was located in the vicinity of the test site. The arrangement of camera on the utility pole is shown in Figure 3-3.

Figure 3-3 Camera with a Fish-Eye Lens Setup on a Utility Pole at Test Site (First Stage)

The data were collected during different seasons of the year to ensure reasonable comparisons. Under various weather conditions, i.e. under normal and adverse weather conditions, the videos were recorded. Normal weather conditions are characterized by dry pavements and adverse weather correspond to the condition of pavement under rain or snow seasons. The movements of vehicles along the test site were captured by a video camera for a time period of more than 48 hours.

The structure of the longitudinal joints and pavement markings at the location of the test site are shown in Figure 3-4. It was observed that the pavement markings were completely faded and the longitudinal construction joints were prominently visible. The construction joints and pavement markings at the test site are drawn in black continuous and white dashed lines in Figure 3-4. The widths of the two lanes of the roads were measured as 12.40 ft. (right lane/target lane) and 11.85 ft. (left lane/adjacent lane) respectively. Longitudinal joints were observed to be positioned at 4.80 ft. and 13.80 ft. from the right curb of the road. The expected position of center-line of vehicles when guided either by pavement markings or longitudinal joints are also indicated in Figure 3-4 by dashed white and black lines respectively.

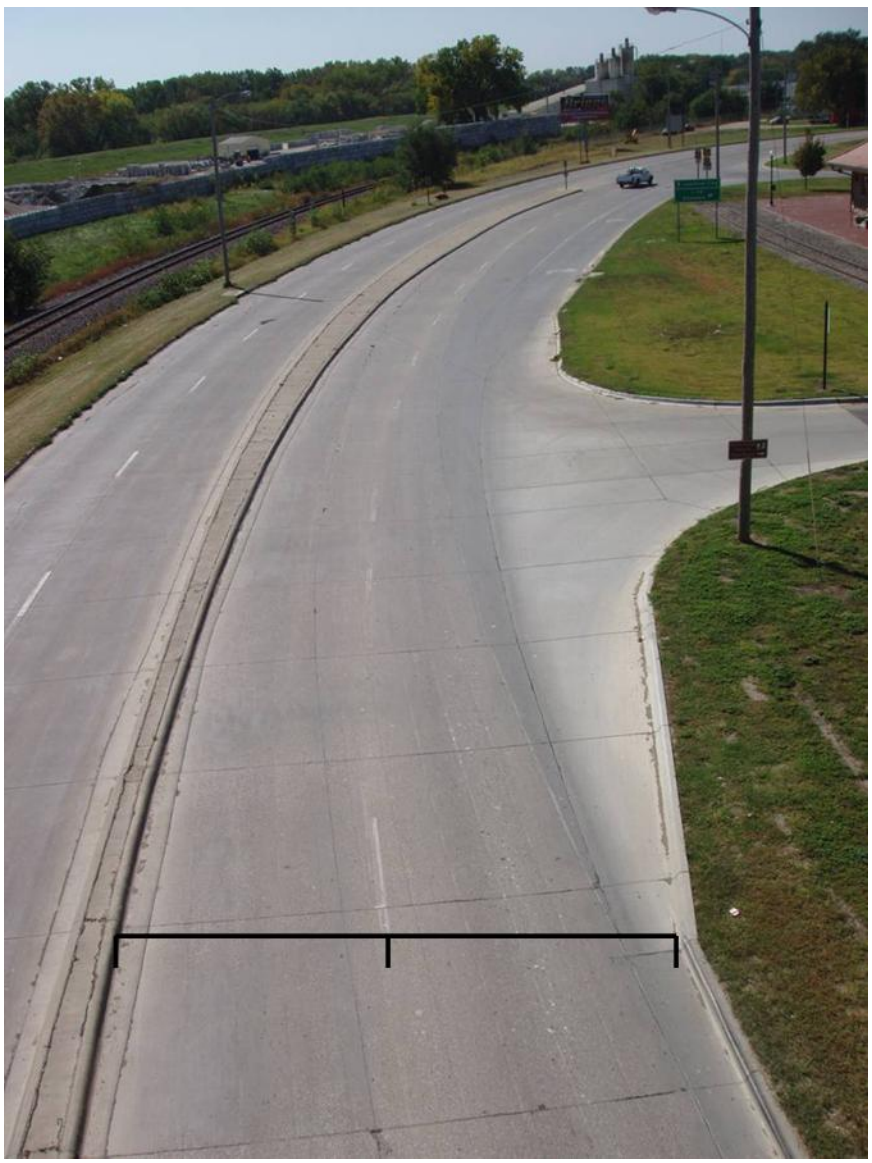
Figure 3-4 Photograph Showing the Joints and Pavement Markings at the Test Site



The right lane, referred to as a target lane was primarily considered while analyzing the data. Main data parameters considered while reducing the data corresponding to the vehicles observed from the video tapes were the distance to the right side of the vehicle, type of the vehicle in the target lane, presence of vehicles in the adjacent lane (left lane), movement of the vehicle immediately after traversing the section of the road having unmatched joints and pavement markings, weather and light conditions at the time of travel, and platoon.

The section of the test site which had the mismatched longitudinal construction joints and pavement markings was considered while reducing the data. A scale was fixed on the television screen for measuring "distance" one of the several data parameters observed. It was setup in such a way that the division "0" started at the right curb of the road, and the final division was at the end of the left lane as shown in Figure 3-5.

Figure 3-5 Scale Setup on the Television Screen for Measuring Distance



The distance to the right side of the vehicle in target lane, from right curb of the road was measured by using the scale setup on the television screen, represented by 'A' in Figure 3-6. Width of the vehicle was also measured, represented by 'B' in Figure 3-6. The summation of distance to the right side of vehicle (A) and half the width of the vehicle (B/2) were computed for obtaining the distance to the center-line of vehicle. These values were measured on the television screen. The scale setup on the screen was in terms of divisions of inches and the scale factor was 1 inch = 12.93 ft. i.e. one inch of measurement on the television screen was equal to 12.93 ft. on the field.

Figure 3-6 Picture Showing the Measurement of Distance on the Television Screen

The distance to the center-line of vehicles measured on the screen was converted into real world dimensions by applying the formulae described in Equation 1.

Equation 1 Distance to the Center-Line of Vehicles

$$\text{DISTANCE}_{screen} = (A + \frac{B}{2})$$

$$\text{DISTANCE}_{field} = (A + \frac{B}{2}) \times Scale\,Factor = (A + \frac{B}{2}) \times 12.933$$

Data was also collected at the test site at Fort Riley Boulevard for conducting a before-after study. An outdoor security camera was used for collecting the data, which was setup on the handrail of Kansas River Bridge. Figure 3-7 shows the position of installation of the security camera along the bridge. A clear view of the site was obtained on setting up the camera at a position shown in Figure 3-7.

Figure 3-7 Security Camera on Kansas River Bridge at the Test Site (Second Stage)

The movements of vehicles were recorded when the pavement markings at the test site were faded, as shown in Figure 3-2. While reducing the data, the details corresponding to the faded pavement markings were reported under the before study. Data were also recorded after the application of the pavement markings at the test site. The condition of the test site on application of the pavement markings is shown in Figure 3-8.

Figure 3-8 Condition of Newly Applied Pavement Markings at Ft. Riley Blvd.

The data reduced under newly laid pavement markings were reported under the after study. The before-after study was conducted to check the influence of better quality pavement markings on the visibility of the drivers, thereby on the lateral position of vehicles. It was also performed to verify whether there was any difference in the mean distance to the center-line of vehicles, under the faded and newly striped pavement markings at the test site.

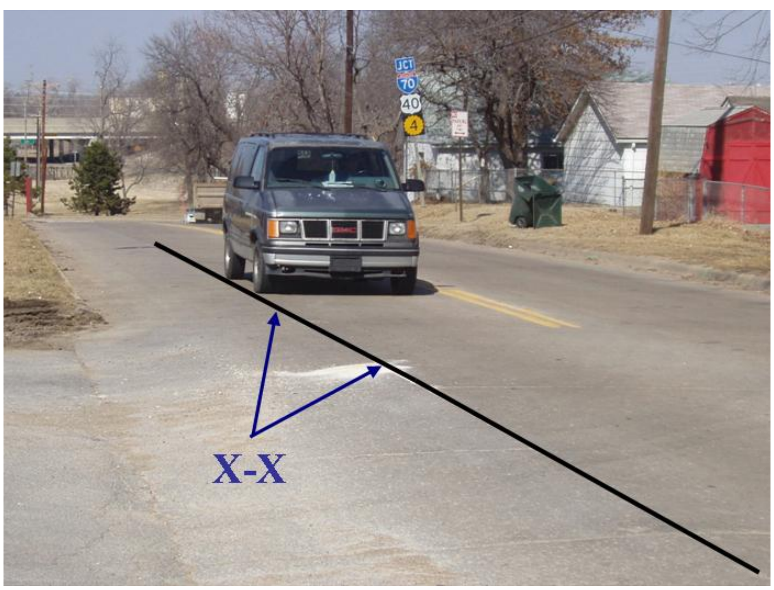
3.2.2 Other Locations

MacVicar Avenue, K-4 Interchange, and I-35/US-75 Interchange in Topeka, Kansas were the other locations identified in addition to the site at Ft. Riley Blvd., Manhattan, Kansas. The pictures of vehicles at these locations were taken by using a still camera. Further details on the test sites are discussed in this subsection.

MacVicar Avenue, Topeka, Kansas

MacVicar Avenue is located at about 0.20 miles south of I-70, in Topeka, Kansas. This section of the city street was constructed approximately forty years ago. The remainder was not constructed and hence, the center-line joint was found to be located in the outside half of the southbound lane. It is now scheduled for reconstruction. Figure 3-9 describes the position of the joint and pavement markings on the site.

Figure 3-9 Position of Joint and Pavement Markings at MacVicar Avenue



The center-line joint is drawn in black color, represented by the section X-X in Figure 3-9. The pavement marking was clearly observed towards the left of the SUV, marked in yellow. The right tires of the vehicle were observed to straddle the joint. Several pictures of the vehicles passing through the test location were taken and the data obtained from the pictures was used for analysis.

K-4/KTA Interchange, Topeka, Kansas

It was observed that the K-4/KTA Interchange, in Topeka, Kansas was a well designed section, having a noticeable longitudinal joint within the driving lane. This location was mainly chosen to determine the position of vehicles along a section of a properly designed road with a clearly visible longitudinal construction joint positioned at certain distance, away from the pavement marking at the test site.

Figure 3-10 Configuration of the Joints and Pavement Markings at the K-4/KTA Interchange

The longitudinal joint is drawn in black color, indicated by two arrows, labeled as section X-X in Figure 3-10. The edge-line of the pavement was marked in yellow. The longitudinal joint was located at a certain distance away from the edge-line. Photographs of the vehicles traveling along this location were captured and the data obtained from them was used for analysis.

I-35/US-75 Interchange, Topeka, Kansas

Pavement markings were observed to be faded at the ramp on the I-35/US-75 Interchange in Topeka, Kansas. Still camera was used for taking the photographs at the location before final striping was done, which was recorded under the before condition. The condition of the test site before final striping is shown in Figure 3-11.

Figure 3-11 Ramp Before Final Striping at I-35/US-75 Interchange

The center-line longitudinal joint is represented by black dashed line. The pavement edge-lines were observed to be faded at this location. The data obtained from the photographs was recorded under the before study. The condition of the pavement markings and center-line joint after the final striping are shown in Figure 3-11.

Figure 3-12 Ramp After Final Striping at I-35/US-75 Interchange

Pavement markings were laid at a different position from the faded pavement markings, closer to the rumble strips. The data obtained from the photographs of the vehicles taken under the condition of newly laid pavement markings was recorded as the after study. Details on the lateral position before and after study are discussed in the section 5-3 of Chapter five.

CHAPTER 4 - Methodology

The information on statistical concepts and tests used for analyzing the data recorded at Fort Riley Boulevard are discussed in Chapter four.

4.1 Background on Hypothesis Testing

Statistical inference is an inference about a population from a random sample drawn from it. The results obtained for a random sample can be generalized to the population. Mean and standard deviation are the main statistical parameters reported either for a sample or for a population.

A hypothesis is formulated whenever a decision on a population or a sample characteristic is to be taken. Mean and standard deviation are the general population characteristics used for describing the data. Statistical tests can be applied for checking the validity of null hypothesis (H_0) against the alternative hypothesis (H_1). The values of the mean and standard deviation of a dataset can be used for validating either hypothesis (*8*).

Test of hypothesis is a procedure for taking a quantitative decision about a process. Two alternatives are possible for a hypothesis testing. Either the null or its alternative can be accepted. The basis of formulating the null hypothesis depends on the type of the statistical test being conducted. For comparing the mean of the sample data to a hypothetical value, null and alternative hypothesis can be formulated as follows. Null hypothesis: The mean value calculated from the data is equal to the hypothetical value, and its alternative hypothesis: The mean value calculated from the data is not equal to the hypothetical value.

Two types of errors may arise in a hypothesis testing, Type I and Type II errors. Type I error may occur when the null hypothesis is rejected even when it is in fact true i.e. H_0 is wrongly rejected. Type II error may occur when the null hypothesis is not rejected even when it is in fact false i.e. H_0 is accepted in spite of it being incorrect. A type I error is often considered to be more serious and therefore is of more importance than a type II error. The hypothesis test procedure is therefore adjusted so that there is a guaranteed low probability of rejecting the null hypothesis wrongly. The significance level of a statistical test, α is based on the probability of type I error, i.e. p(type I error) = α . Further details of the statistical testing and other concepts are explained in the following sections.

For the present study, null and alternative hypothesis were formulated, which are described as follows: Null Hypothesis: The mean distance to the center-line of vehicles is equal to a hypothetical mean value, and alternative hypothesis: The mean distance to the center-line of vehicles is not equal to a hypothetical mean value.

4.1.1 General Procedure Adopted in Hypothesis testing

Hypothesis testing can be used for taking a decision on a sample characteristic. Mean and standard deviation are normally reported for a sample. The equality of observed and expected means can be checked by applying a hypothesis test. Details on the procedure used in hypothesis testing are as follows (*8*):

1. The null and alternative hypotheses are formulated. The mean value calculated from the data is compared to a hypothetical value for arriving at a conclusion.
2. Select a level of significance (α). Normally considered as 0.05.
3. The sample size is determined.
4. Data is collected after determining the sample size.
5. A ‘t’ or a ‘z’ statistic is computed from the sample data used for analyzing the mean and standard deviation.
6. Either the‘t’ or ‘z’ distribution tables is used for checking the validity of the null or alternative hypothesis.
7. A decision is made on:
   a) The null hypothesis is rejected and its alternative hypothesis is accepted or
   b) Fail to reject the null hypothesis and therefore it is stated that there is no enough evidence to validate the alternative hypothesis.

4.2 Types of t-tests Used in Data Analysis

Either the ‘z’ or ‘t’ tests may be used for arriving at a conclusion regarding the acceptance or the rejection of the null hypothesis. If the data corresponds to a population then, a ‘z’ statistic can be used. Since data for this study was a random sample of a population, t-tests were used for performing the analysis. The t-test can be applied if the data satisfies the condition of normal distribution. The Anderson-Darling test may be applied for checking the normality of data. For comparing the mean value of a single dataset to a hypothetical value, a one-sample t-test can be used. For comparing the mean values of two different groups of data, an independent group t-test can be used. The details regarding various t-tests used in analyzing the data are discussed in the subsections 4.2.1 and 4.2.2 of Chapter four.

4.2.1 Details on the One-Sample t-test

If the mean value calculated from the data needs to be compared to a hypothetical value, a one-sample t-test can be used. Null and alternative hypotheses are formulated before computing the t-value. Null Hypothesis: The mean of the data is equal to a hypothetical value and Alternative Hypothesis: The mean of the data is not equal to the hypothetical value, are assumed. The values of the mean and standard deviation are calculated from the data. The level of significance, α is assumed. The t-statistic is computed from the data by using the formula described in the Equation 2 **(***9***)**.

Equation 2 Student's t-test for Comparing the Observed and Expected Mean Values

$$t = \frac{(X - \mu)}{\left(\frac{s}{\sqrt{n}}\right)}$$

Where,

t	=	Estimated t-value
X	=	Observed mean of the data
μ	=	Expected mean
s	=	Standard deviation of the data
n	=	Number of observations

The t-value can be obtained by knowing the level of significance and the degrees of freedom. The level of significance is normally assumed as 0.05. The degrees of freedom for a one sample Student's t-test are the number of observations minus 1 i.e. (n-1). The critical t-value is obtained from the standard t-distribution table corresponding to a level of significance of 0.05 and degrees of freedom (n-1). The acceptance or rejection of null hypothesis depends on the magnitudes of the estimated and critical t-values.

If the t-value computed by using the Equation 2 is greater than the critical t-value obtained from the t-distribution table, the null hypothesis is rejected. It implies that the alternative hypothesis can be accepted. If the estimated t-value is lesser than the critical t-value, the null hypothesis is accepted and its alternative is rejected.

In addition to the t-test performed manually, some statistics software can also be used for conducting the one-sample t-test (*10*). Statistical Analysis Software (SAS) has pre-defined library functions for performing different statistical tests. The probability value (p-value) corresponding to the t-test are used in validating either hypotheses. If p-value associated with the t-test, $p>0.05$, the null hypothesis is accepted and its alternative is rejected. If $p<0.05$, the alternative hypothesis is accepted and its null is rejected.

4.2.2 Details on the Independent Group t-test

For comparing means of two groups, an independent group t-test is used. The independent group t-test assesses whether the means of two groups are statistically significant or not. Null Hypothesis: There is no difference between the means of the two groups and Alternative Hypothesis: The difference between the means of the two groups is statistically significant, are formulated.

Statistical Analysis Software (SAS) can be used for performing the independent group t-test. An appropriate library function in SAS can be used for comparing the means of the two groups of data. Two t-values are reported in the output, one under the assumption of equal variance and the other under the assumption of unequal variance. The formula shown in the Equation 3 is used for computing the t-value under the assumption of equal variance.

Equation 3 Computation of t-value Under the Assumption of Equal Variance

$$t = \frac{(x_1 - x_2)}{\sqrt{s^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Where,

t	=	Calculated t-value
x_1	=	Mean value of the first group
x_2	=	Mean value of the second group

s^2	=	Pooled variance
n_1	=	Number of observations of the first group
n_2	=	Number of observations of the second group

The degrees of freedom for the pooled method of equal variance are (n_1+n_2-2). The formula for computing the pooled variance is shown in the Equation 4.

Equation 4 Formula for Calculating Pooled Variance

$$s^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{(n_1 + n_2 - 2)}$$

Under the assumption of unequal variance, the t-value is calculated by using the formula described in the Equation 5.

Equation 5 Computation of t-value Under the Assumption of Unequal Variance

$$t = \frac{(x_1 - x_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Where,

t	=	t-value
x_1	=	Mean value of the first group
x_2	=	Mean value of the second group
s_1^2	=	Variance of the first group
s_2^2	=	Variance of the second group
n_1	=	Number of observations of the first group
n_2	=	Number of observations of the second group

The Folded F-form statistic is computed for checking the equality of variance. Null Hypothesis: The variance of the first group is equal to the variance of the second group and

Alternative hypothesis: The variances of the two groups are not equal are formulated. The formula in the Equation 6 is used for computing the F-statistic.

Equation 6 Folded F-form Statistic for Checking Equality of Variance

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

Where,

F	=	Folded F-form statistic
s_1^2	=	Variance of the first group
s_2^2	=	Variance of the second group

If p-value associated with the F-test is greater than 0.05, p>0.05, the t-value corresponding to the pooled method of equal variance is reported as the appropriate test value. If p<0.05, the t-value corresponding to either Satterthwaite or the Cochran and Cox approximation method of unequal variance is reported as the test value. The degrees of freedom for Satterthwaite's approximation are computed by using the Equation 7.

Equation 7 Degrees of Freedom for Satterthwaite's Approximation

$$df = \left(\frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{(n_1 - 1)} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{(n_2 - 1)}} \right)$$

The Equations 3 through 7 are used by SAS program for computing the values associated with the independent t-tests (*10*).

The p-values of the corresponding t-tests are used for validating the null or alternative hypothesis. If p>0.05, the null hypothesis is accepted and its alternative is rejected. If p<0.05, the alternative hypothesis is accepted and its null is rejected. The program codes generated for performing the one-sample and independent group t-tests by using SAS are provided in the

Appendix D. In addition to the code, the outputs from the corresponding tests are also provided for additional information.

4.3 Data Modeling Using Regression Analysis

As an extension to the statistical tests performed in checking the differences for verifying the effects of the unmatched longitudinal construction joints and pavement markings on the lateral position of the vehicles from the Ft. Riley data, a regression model was developed for predicting the distance from other parameters. All the data parameters reduced from the video tapes were used in the regression model.

Regression analysis is defined as the estimation of prediction of the value of one variable from the values of other given variables (*11*). The relationship between a dependent variable 'Y' and several independent variables 'X_i', i=1,2,3,……,p and a random term ε is obtained from the regression model. The model of linear regression is shown in the Equation 8.

Equation 8 Model of Linear Regression

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots\dots\dots + \beta_p X_p + \varepsilon$$

β_0 is the intercept, β_i s are the parameters of the respective independent variables and p is the number of parameters which are to be estimated in the linear regression. The dependent variable 'Y' is assumed to have a linear relationship with the independent variables X_is (*12*).

The independent variables which are assumed to make an important contribution to the effectiveness of the relationship are included in the regression equation. The other condition which needs to be satisfied is that the independent variables should be readily measurable or observable (quantitative or qualitative). If the distribution of the values of the dependent variable about the means is normal, then, the method of least squares was found to be the efficient method for estimating the parameters of the independent variables (β values).

The method of least squares estimation is a procedure for estimation of parameters, such that the sum of the squares of the vertical deviations is minimized. If the dataset contains 'n' values of the one dependent and 'p' independent variables, the expression for the sum of the squares to be minimized is shown by the Equation 9 (*12*).

Equation 9 Least Squares Estimation

$$S(y-\beta_0-\beta_1 x_1-........-\beta_p x_p)^2$$

Upon solving the Equation 8 and substituting the necessary values, the overall analysis of variance table as shown in Table 4-1.

Table 4-1 The Overall Analysis of Variance Table

<table>
<tr><td>Source</td><td>Degrees of Freedom (df)</td><td>Sum of Squares (SS)</td><td>Mean Square (MS)</td><td>F- Value</td><td>p-value</td></tr>
<tr><td>Regression</td><td>p</td><td>SS_{reg}</td><td>SS_{reg} / p</td><td rowspan="2">MS_{reg} / σ^2</td><td rowspan="2"></td></tr>
<tr><td>Residual</td><td>(n-p-1)</td><td>RSS</td><td>σ^2 = RSS / (n-p-1)</td></tr>
</table>

The overall analysis of variance table tests the null hypothesis that the parameters, $\beta_p=0$ to the alternative hypothesis, at least one parameter of $\beta_p \neq 0$. The p-value corresponding to the F-test is used for the validation of the either hypotheses. If $p>0.05$, the null hypothesis is accepted, which indicates that all the parameters are '0'. If $p<0.05$, the null hypothesis is rejected which implies that some of the parameters are non-zero. The R^2 value, computed by the formula from the Equation 10 gives the proportion of variability in the dependent variable explained by the regression on the terms. It is the square of the correlation between the observed and fitted value of the dependent variable.

Equation 10 Coefficient of Determination, R^2

$$R^2 = \frac{SS_{reg}}{S_{YY}} = \left(1 - \frac{RSS}{S_{YY}}\right)$$

The value of $R^2 = 1$ indicates perfect fit to the data, while $R^2 = 0$ indicates that the independent variables do not explain the data. The value of R^2, multiplied by 100 can be used in explaining the percentage of variability of the dependent variable in terms of the independent variables.

The data recorded at Ft. Riley Blvd., during the first stage, under the obliterated pavement markings was considered for developing the regression model. The parameters observed while reducing the data from the video tapes were, the types of vehicles (passenger cars, vans, pickups and heavy vehicles), presence of a vehicles in the adjacent lane (yes or no), movement of the vehicle (straight or right), weather condition (adverse or normal), distance from the right curb of the road to the right lateral side of the vehicle, and, platoon of vehicles (yes or no). Distance was treated as the dependent variable and the other parameters were considered to be the independent variables. It was found that the variable "DISTANCE" was dependent upon the type of the vehicle, presence of vehicles in the adjacent lane, the movement of the vehicle, weather condition, and, the platoon effect.

The types of variables involved in the model were both continuous and categorical. Continuous variables can be quantified but, the categorical variables are qualitative in nature. The latter terms may also be treated as binary variables as they have only two options, yes or no. The details regarding the dependent and independent variables are provided in Table 4-2.

Table 4-2 Description of Variables Used in the Regression Model

Variable Name	Description	Value
WEATHER	Weather condition at the time of data recording.	1 = Normal Weather 0 = Adverse Weather
ADJVEH	The presence of vehicles adjacent to the vehicle traveling in the target lane at the time of data recording.	1 = Yes 0 = No
DIRN	The movement of vehicles immediately after traversing the section of the road having the unmatched longitudinal construction joints and pavement markings.	1 = Straight 0 = Right
PLATOON	A number of vehicles following the vehicle traveling in the target lane.	1 = Yes 0 = No
DISTANCE	The lateral position of the vehicle traveling in the target lane measured from the right curb of the road.	Several values, measured from the video tapes.

In addition to the variables defined in Table 4-2, the types of vehicles were also considered while reducing the data. Passenger cars (P), vans (V), pickups (T) and heavy vehicles (H) were observed to be traveling along the Ft. Riley Blvd. CA, VA, and PU were defined for categorizing the data on the basis of the types of vehicles. If the vehicle observed was a passenger car, the variable CA was coded as ‘1’ else as ‘0”. Likewise, the other vehicles were coded. Table 4-3 is provided for giving the information on the coding of vehicle variables.

Table 4-3 Coding of Variables Based on the Types of Vehicles Observed

Vehicle	Value	PA	VA	PU	HV
Passenger Cars	P	1	0	0	0
Vans	V	0	1	0	0
Pickups	PU	0	0	1	0

Forward selection, backward elimination, and stepwise regression were the different types of methods used in regression modeling. Further details on the terms involved in the regression model, and, the program for executing the model using SAS are included in the Appendix E.

CHAPTER 5 - Analysis Results

The analysis of the data collected at the test site at Fort Riley Boulevard in the first and second stages is discussed in the sections 5.1 and 5.2. The results obtained for the data collected at other locations is provided in the section 5.3. The section 5.4 of Chapter five contains the information on the regression model developed for the data collected at Ft. Riley Blvd.

5.1 Analysis of the Data at Fort Riley Boulevard – First Stage

Data corresponding to 14,050 vehicles were obtained from the video tapes recorded in the first stage of data collection at Ft. Riley Blvd. Prior to the analysis, the data was checked for the assumption of normality by applying the Anderson-Darling test. Null hypothesis: The data does not fit the normal distribution and Alternative hypothesis: The data fits normal distribution was assumed. The p-value, Pr>A-Square was obtained as $p<0.005$. Since $p<0.05$, the null hypothesis was rejected and its alternative was accepted. The results of the Anderson-Darling test indicated that data fitted normal distribution. Since the data fitted normal distribution, t-tests were applied.

5.1.1 One-Sample t-tests Applied for Ft. Riley Blvd. Data

Initially, entire dataset corresponding to 14,050 vehicles reduced from the video tapes were used in the analysis. The mean distance calculated for the entire dataset was used for carrying out the one-sample t-test by applying the following values in Equation 2 in the subsection 4.2.1.

X = 7.06 ft.

μ = 6.20 ft.

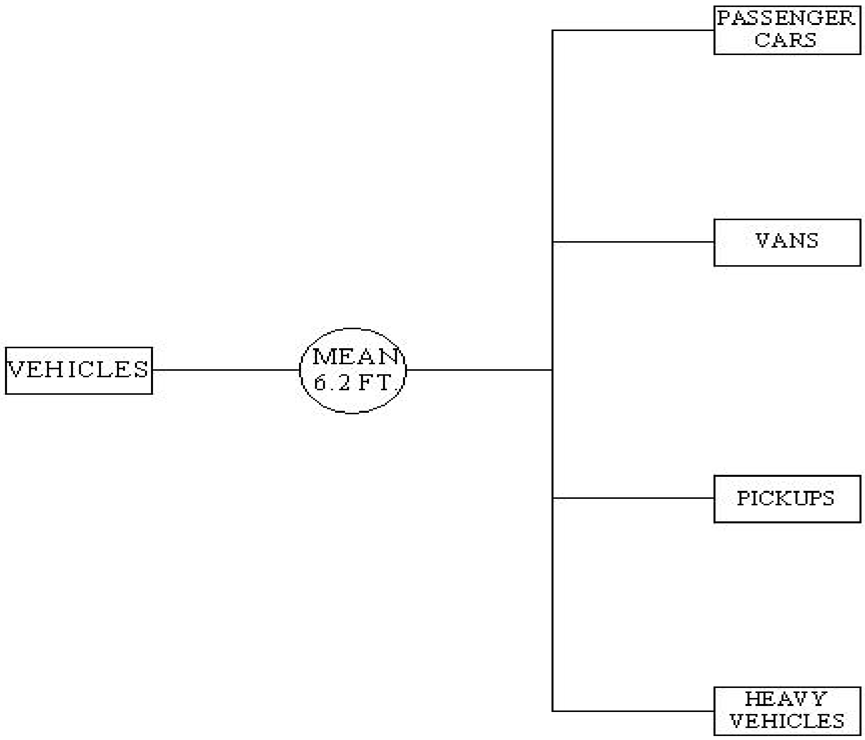
s = 1.61 ft.

n = 14,050

A one-sample t-test was performed under the null hypothesis: The mean distance to the center-line of travel for the vehicles is equal to 6.20 ft. and the alternative hypothesis: The mean distance to the center-line of travel for the vehicles is not equal to 6.20 ft. The t-statistic was obtained as 63.72 by substituting the values of the respective parameters in the Equation 2. The obtained t-value was compared to the critical value of 1.96, obtained from the t-distribution table corresponding to 14,049 degrees of freedom and a level of significance of 0.05. As the observed t-value was greater than the critical t-value obtained from the t-distribution table, the null hypothesis was rejected and its alternative was accepted. From the test results, it was inferred that the mean distance to the center-line of travel for the vehicles was different from the hypothesized mean value of 6.20 ft. If the vehicles were assumed to be guided by the pavement markings alone, the expected mean distance to the center-line of travel for the vehicles should have been 6.20 ft., which is half the width of target lane. Since the longitudinal construction joints were not coincident with the pavement markings, the mismatch may have guided the drivers to position their vehicles away from the expected center-line of travel. Therefore it was implied that there would have been an effect of the unmatched longitudinal construction joints and pavement markings on the lateral position of vehicles.

The data was categorized into several subsets for affirming the effects of unmatched longitudinal construction joints and pavement markings on the lateral position of vehicles. The primary classification was on the basis of the types of vehicles. The data corresponding to the passenger cars, vans, pickups and heavy vehicles reduced from the video tapes were separated for performing one-sample t-tests. Each subset of data was tested for a hypothesized mean of 6.20 ft. Null hypothesis: The mean distance to the center-line of travel for the vehicles (passenger car, van, pickup, and heavy vehicle) is equal to 6.20 ft. and alternative hypothesis: The mean distance to the center-line of travel for the vehicles is not equal to 6.20 ft. were formulated. The tree diagram in Figure 5-1, describes the data tested under the one-sample t-test.

Figure 5-1 Ft. Riley Blvd. Data Classified on the Basis of the Types of Vehicles



The one-sample t-test was applied for data classified on the basis of the types of vehicles. The mean, standard deviation and estimated t-values are reported for the corresponding types of vehicles. The critical t-values for various types of vehicles for a known sample size and level of significance were obtained from the reference t-distribution table, are also reported in Table 5-1.

Table 5-1 Details of the One Sample t-test Based on the Types of Vehicles

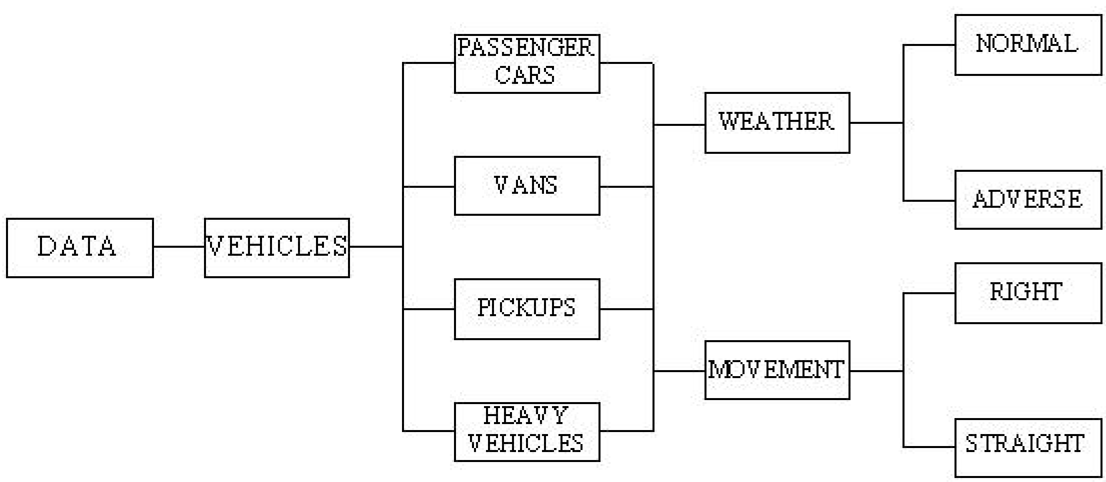
Description	Sample Size	Mean (Ft)	Std. Dev. (Ft)	t-value		p-value
				Estimated	Critical	
All vehicles	14,050	7.06	1.61	63.72	1.96	<0.0001
Passenger cars	5,878	6.36	1.44	8.36	1.96	<0.0001
Vans	4,055	7.42	1.49	51.85	1.96	<0.0001
Pickups	3,352	7.55	1.48	52.92	1.96	<0.0001
Heavy vehicles	765	8.50	1.61	39.55	1.96	<0.0001

The estimated t-values for all the categories of vehicles were greater than the critical t-values. Since the p-values associated with the corresponding t-test were less than 0.05, $p<0.05$, the null hypothesis: The mean distance to the center-line of travel is equal to 6.20 ft. was rejected and its alternative was accepted. It implied that the mean distance to the center-line of travel for the different types of vehicles was different from 6.20 ft.

If the vehicles were assumed to be guided by the pavement markings alone, their expected mean distance to the center-line of travel would have been 6.20 ft. But, the mean values from the data were observed to be different. It was also concluded from the alternative hypothesis that the actual value was not equal to the expected value. Since the longitudinal construction joints and pavement markings at the test site were not coincident, there would have been a possibility for the drivers to be guided by the mismatch, leading them to position their vehicles away from the expected center-line of travel. It was inferred that there was an effect on the lateral position of the vehicles due to the unmatched longitudinal construction joints and pavement markings.

The tree diagram in Figure 5-2 represents the classification of the data recorded at the test site at Ft. Riley Blvd. corresponding to the first stage.

Figure 5-2 Classification of the Data Recorded at Test Site (First Stage)



One-sample t-tests were performed for the individual categories of data i.e. the data corresponding to passenger cars, vans, pickups and heavy vehicles traveling under different weather conditions and vehicle movements observed. The t-tests were applied for the vehicle data under normal weather conditions. The t-tests were also applied for the other categories of data i.e. vehicles traveling under adverse weather conditions, those going straight, and those taking a right turn. The null hypothesis: The mean distance to the center-line of travel of the vehicles (passenger cars, vans, pickups and heavy vehicles) under various categories (normal weather, adverse weather, moving straight, and taking a right turn) is equal to 6.20 ft. and the alternative hypothesis: The mean distance to the center-line of travel for different types of vehicles under various categories is not equal to 6.20 ft. were formulated. Instead of using the Equation 2 described in the subsection 4.2.1 for performing the one-sample t-test, a program code was written by using the library function of the SAS software. The SAS code for the one-sample t-test is included in the Appendix C. The mean, standard deviation, t-value and p- value corresponding to various categories of the data are reported in Table 5-2 through Table 5-5.

Table 5-2 Details of the One-Sample t-test for the Vehicle Data under Normal Weather

Description	Sample Size	Mean (Ft)	Std. Dev. (Ft)	t-value	p-value
All vehicles	8,518	7.27	1.69	57.45	<0.0001
Passenger cars	3,588	6.52	1.53	12.58	<0.0001
Vans	2,282	7.66	1.61	43.37	<0.0001
Pickups	2,142	7.75	1.58	45.39	<0.0001
Heavy vehicles	507	8.79	1.71	34.03	<0.0001

Table 5-3 Details of the One-Sample t-test for the Vehicle Data under Adverse Weather

Description	Sample Size	Mean (Ft)	Std. Dev. (Ft)	t-value	p-value
All vehicles	5,532	6.76	1.37	30.09	<0.0001
Passenger cars	2,290	6.04	1.23	-3.98	<0.0001
Vans	1,773	7.10	1.26	29.90	<0.0001
Pickups	1,210	7.21	1.21	28.88	<0.0001
Heavy vehicles	258	8.13	1.27	24.40	<0.0001

Table 5-4 Details of the One-Sample t-test for the Vehicles Going Straight

Description	Sample Size	Mean (Ft)	Std. Dev. (Ft)	t-value	p-value
All vehicles	8,714	7.16	1.59	56.38	<0.0001
Passenger cars	3,657	6.49	1.42	12.29	<0.0001
Vans	2,552	7.52	1.51	44.42	<0.0001
Pickups	2,057	7.64	1.48	43.86	<0.0001
Heavy vehicles	448	8.44	1.69	28.07	<0.0001

Table 5-5 Details of the One-Sample t-test for the Vehicles Taking a Right Turn

Description	Sample Size	Mean (Ft)	Std. Dev. (Ft)	t-value	p-value
All vehicles	5,336	6.90	1.61	29.88	<0.0001
Passenger cars	2,221	6.14	1.44	-1.99	0.046
Vans	1,503	7.23	1.45	27.51	<0.0001
Pickups	1,295	7.42	1.46	30.02	<0.0001
Heavy vehicles	317	8.58	1.48	28.60	<0.0001

The p-values of the corresponding t-tests are directly reported in the SAS output. The value of the level of significance, α is a default value of 0.05 for the SAS command. The decision to either accept or reject the null hypothesis can be obtained by knowing the p-values of the corresponding t-tests. If $p>0.05$, the null hypothesis is accepted and its alternative is rejected. If $p<0.05$, the alternative is accepted and the null hypothesis is rejected.

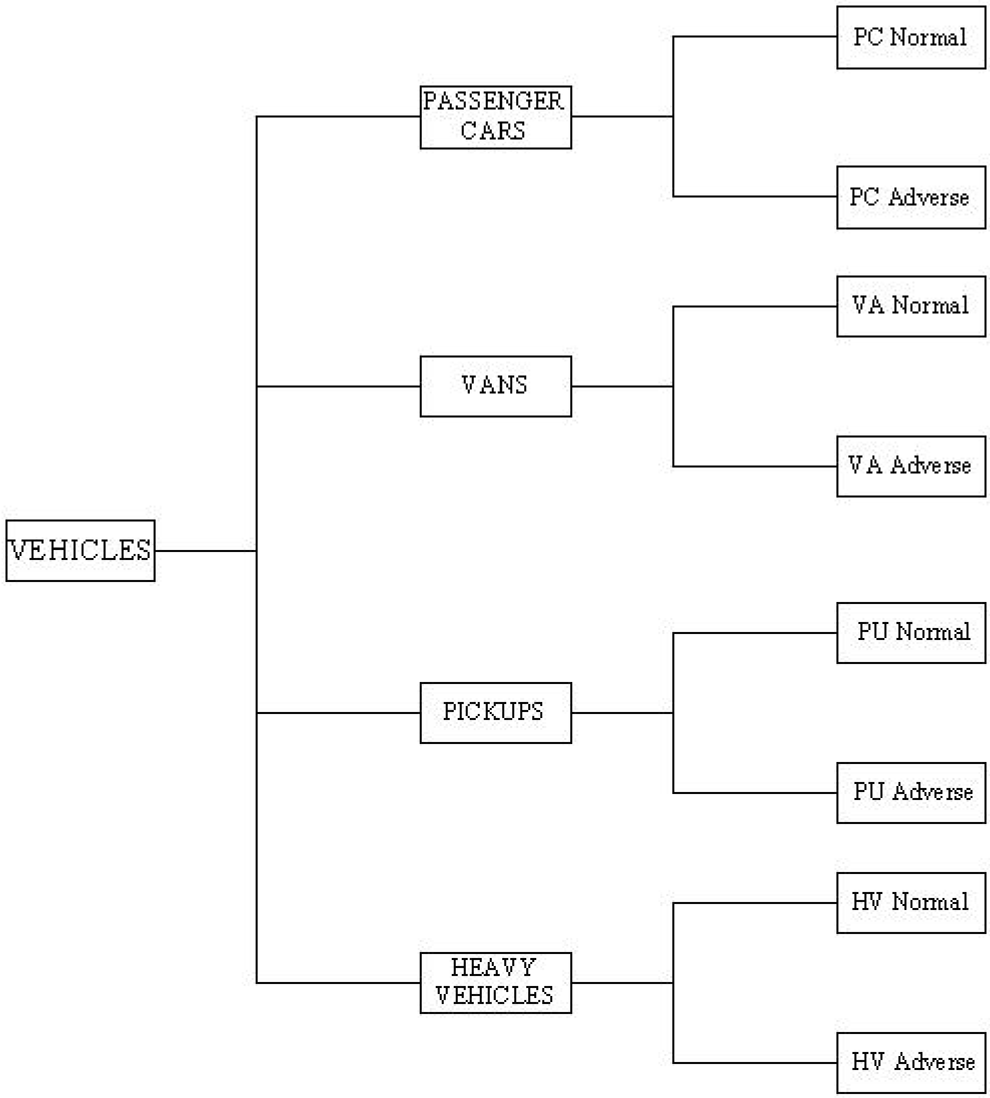
Since the p-values corresponding to all the t-tests applied for the subsets of the data at Ft. Riley Blvd. were less than 0.05, $p<0.05$, the null hypothesis was rejected and its alternative was accepted. It implied that the mean distance to the center-line of vehicles was not equal to 6.20 ft. It was inferred from the results of the t-tests that the unmatched longitudinal construction joints and pavement markings at the test site at Ft. Riley Blvd. may have had an effect on the lateral position of vehicles as difference was observed in the actual and expected distance to the center-line of travel of vehicles.

5.1.2 Independent Group t-tests Applied for Ft. Riley Blvd. Data

Several comparisons were made for the subsets of the data categorized on the basis of weather conditions during travel, movement of the vehicles immediately after passing the section of the road which had unmatched longitudinal construction joints and pavement markings, the presence of vehicles in the adjacent lane, and, the platoon factor. The details are discussed in the subsection 5.1.2 of Chapter five.

The data was classified on the basis of weather conditions i.e. vehicles traveling under normal and adverse weather conditions. The vehicle data under normal weather was compared to the data under adverse weather conditions. The tree diagram in Figure 5-3 describes the classification of the data for applying the independent group t-tests, with respect to weather conditions.

Figure 5-3 Ft. Riley Blvd. Data Classified by Weather Condition



Independent group t-tests were applied for analyzing the data under the null hypothesis: There is no difference between the mean distances to the center-line of travel for the vehicles under normal and adverse weather conditions and the alternative hypothesis: The difference between the mean distances to the center-line of travel of vehicles under normal and adverse weather conditions is statistically significant. SAS code was generated for computing the t-statistic, which is included in the Appendix C. It uses the Equation 3 through Equation 6 for calculating the values associated with the independent group t-tests. The values obtained on applying the independent group t-tests for the data represented by Figure 5-3 are reported in Table 5-6.

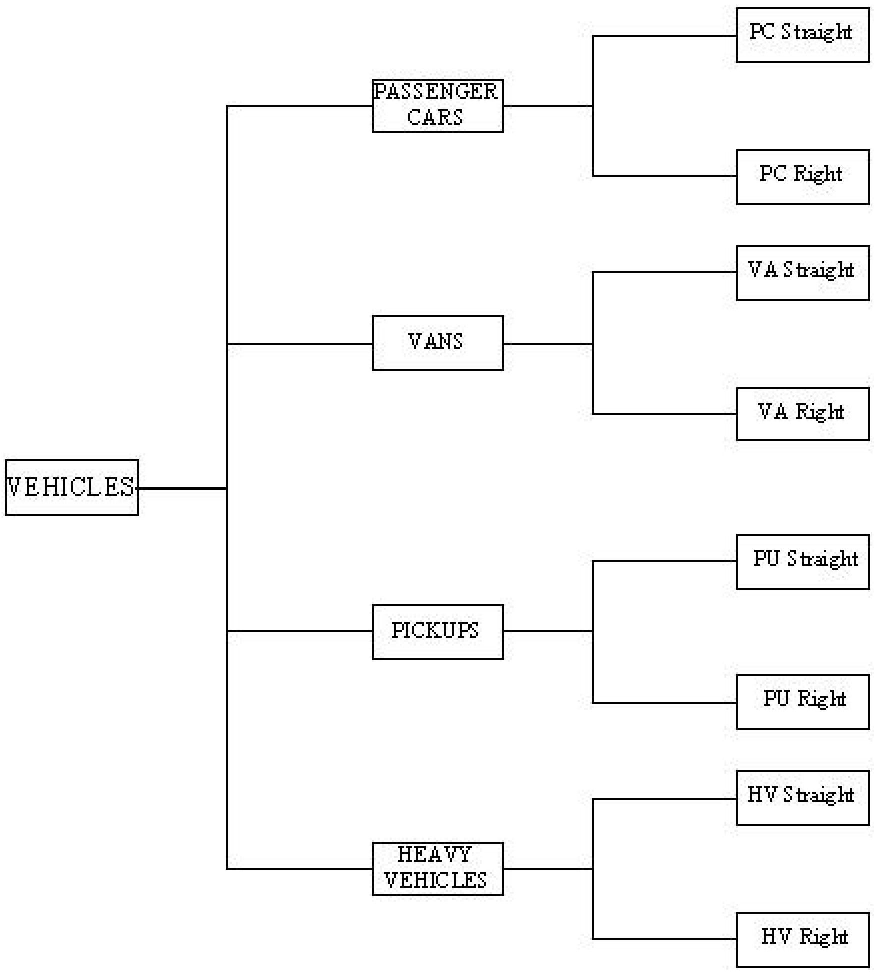
Table 5-6 Details of the Independent Group t-test for the Data Classified on the Basis of Weather Conditions

Details	Weather	Size	Mean (Ft)	Std Dev. (Ft)	F-test		t-test	
					F-value	p-value	t-value	p-value
All vehicles	Normal	8,518	7.27	1.72	1.57	<0.0001	19.62	<0.0001
	Adverse	5,532	6.76	1.37				
Passenger Cars	Normal	3,588	6.52	1.53	1.55	<0.0001	11.70	<0.0001
	Adverse	2,290	6.10	1.23				
Vans	Normal	2,282	7.66	1.61	1.62	<0.0001	12.47	<0.0001
	Adverse	1,773	7.10	1.26				
Pickups	Normal	2,142	7.75	1.62	1.27	<0.0001	11.09	<0.0001
	Adverse	1,210	7.21	1.26				
Heavy Vehicles	Normal	507	8.79	1.71	1.71	<0.0001	5.47	<0.0001
	Adverse	258	8.13	1.27				

The alternative hypothesis was accepted as the p-values were less than 0.05, $p<0.05$. All the results for the data tested on the basis of weather conditions were found to be statistically significant. Since the p-values associated with the F-tests were less than 0.05, the t-values corresponding to the Satterthwaite or Cochran and Cox Approximation method of unequal variance were reported as the test values. From the p-values of the corresponding t-tests, it was inferred that the mean distances to the center-line of travel of the vehicles under normal weather was different from those under adverse weather conditions. With 95% confidence, it was concluded that there was a statistically significant difference between the mean distances to the center-line of travel of vehicles classified on the basis of weather conditions.

The data was classified on the basis of the movement of vehicles observed at the test site. Drivers were continuing along the west of Ft. Riley Blvd. (going straight) and also moving onto the southbound ramp (taking a right turn), the instant they exited the section of the site having the unmatched longitudinal construction joints and pavement markings. As in the case of the vehicle data tested on the basis of weather conditions, independent group t-tests were applied for the data classified with respect to the movement of the vehicles. The tree diagram in Figure 5-4 describes the classification of the data on the basis of movement for applying the independent group t-tests.

Figure 5-4 Ft. Riley Blvd. Data Classified with Respect to the Movement



Independent group t-tests were applied for analyzing the data under the null hypothesis: There is no difference between the mean distances to the center-line of travel for the vehicles going straight and those taking a right turn and the alternative hypothesis: The difference between the mean distances to the center-line of travel of vehicles going straight and those taking a right turn is statistically significant. The values obtained on applying the independent group t-tests for data represented by Figure 5-4 are reported in Table 5-7.

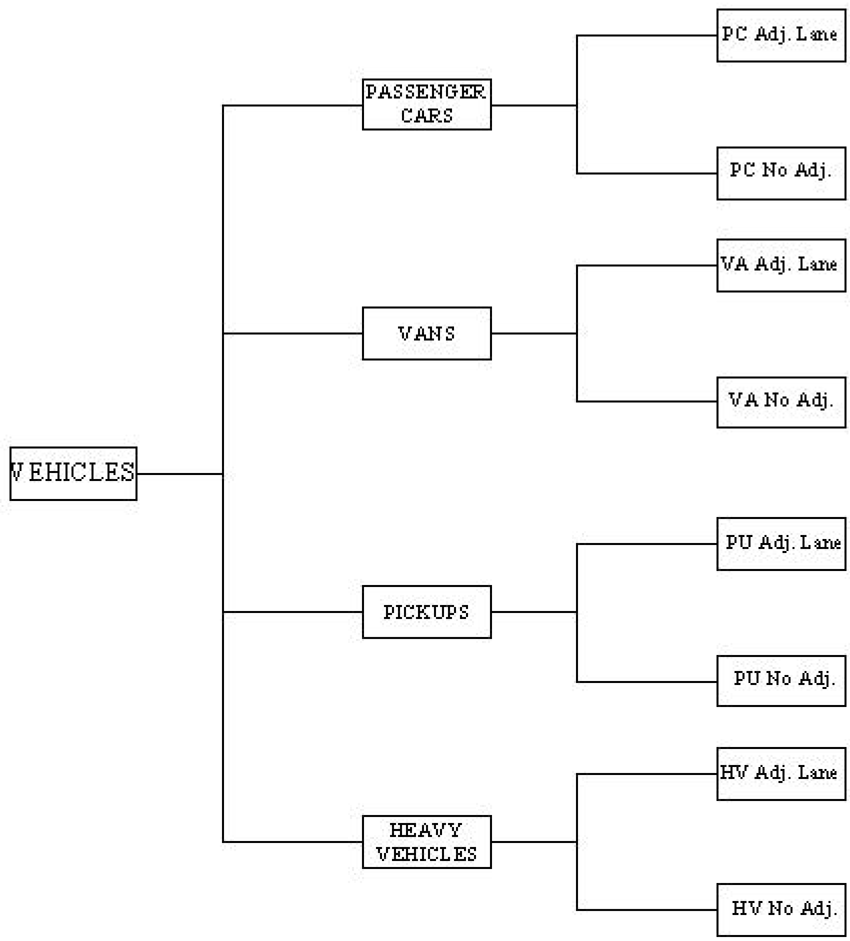
Table 5-7 Details of the Independent Group t-test for the Data Classified on the Basis of Movement

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

The alternative hypothesis was accepted as the p-values were less than 0.05, $p<0.05$, except for heavy vehicles. The other results for the data tested on the basis of movement were found to be statistically significant. Since the p-values associated with the F-tests were greater than 0.05, the t-values corresponding to the pooled method of equal variance were reported as the test values. From the p-values corresponding to the t-tests, it was inferred that the mean distances to the center-line of travel of the vehicles going straight was different from those vehicles taking a right turn. With 95% confidence, it was concluded that there was a statistically significant difference between the mean distances to the center-line of travel of vehicles classified on the basis of movement.

Independent group t-tests were applied to check whether there was a difference in the mean distance to the center-line of vehicles having vehicles in their adjacent lane to those without any vehicles in their adjacent lane. Likewise, the categorization of data was carried out and independent group t-tests were applied for the different types of vehicles, represented by Figure 5-5.

Figure 5-5 Ft. Riley Blvd. Data Classified with Respect to the Vehicles in the Adjacent Lane



Independent group t-tests were applied for analyzing the data under the null hypothesis: There is no difference between the mean distances to the center-line of travel for the vehicles having vehicles in the adjacent lane and those without the vehicles in the adjacent lane and the alternative hypothesis: The difference between the mean distances to the center-line of travel for the vehicles having vehicles in the adjacent lane and those without vehicles in the adjacent lane is statistically significant. The values obtained on applying the independent group t-tests are reported in Table 5-8.

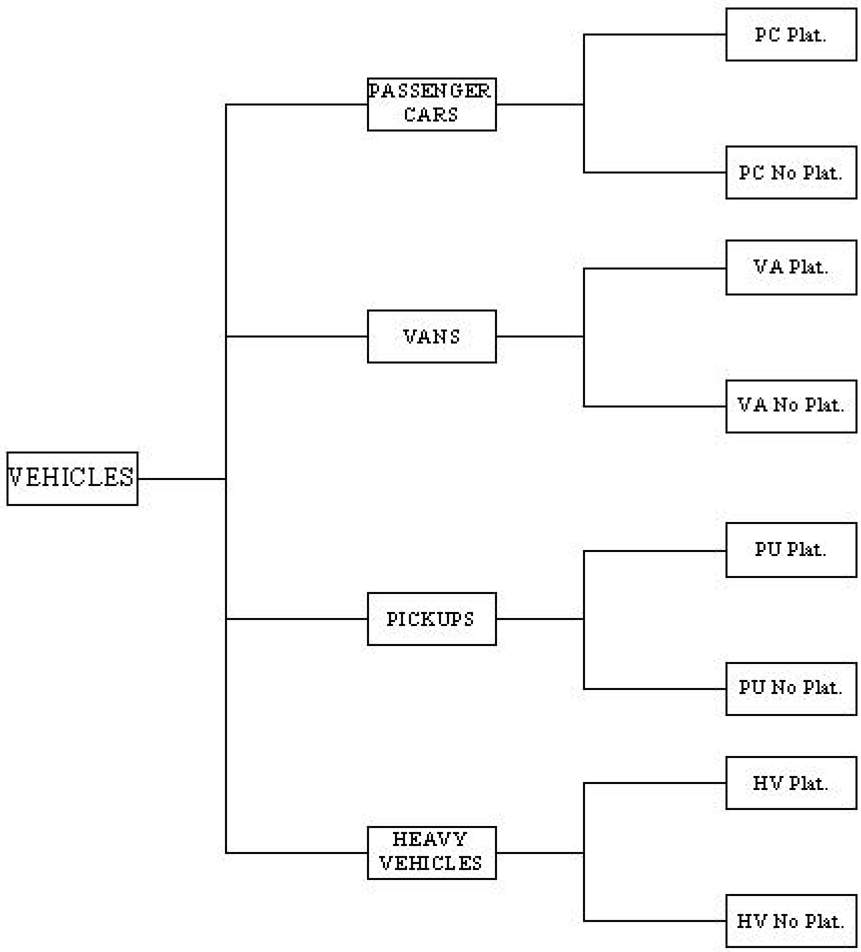
Table 5-8 Details of the Independent Group t-test for the Data Classified on the Basis of Vehicles in the Adjacent Lane

Details	Vehicles adj. lane	Size	Mean (Ft.)	Std Dev. (Ft.)	F-test		t-test	
					F-value	p-value	t-value	p-value
All vehicles	No	12,591	7.11	1.61	1.11	0.0072	9.47	<0.0001
	Yes	1,459	6.70	1.53				
Passenger Cars	No	5,286	6.40	1.44	1.12	0.0620	7.12	<0.0001
	Yes	592	5.96	1.36				
Vans	No	3,663	7.46	1.50	1.22	0.0100	6.13	<0.0001
	Yes	392	7.01	1.36				
Pickups	No	2,976	7.60	1.48	1.11	0.1972	4.83	<0.0001
	Yes	376	7.20	1.41				
Heavy Vehicles	No	666	8.57	1.62	1.23	0.1976	3.04	0.0024
	Yes	99	8.04	1.46				

The alternative hypothesis was accepted as the p-values were less than 0.05, $p<0.05$. All the results for the data tested on the basis of vehicles in the adjacent lane were found to be statistically significant. The p-values associated with the F-tests for the passenger cars, pickups and heavy vehicles were greater than 0.05. Hence, the t-values corresponding to the pooled method of equal variance were reported as the test values of these vehicles. For the other vehicles, t-values corresponding to the Satterthwaite or Cochran and Cox Approximation method of unequal variance were reported. From the p-values of the corresponding t-tests, it was inferred that the mean distances to the center-line of vehicles which were traveling with vehicles in adjacent lane was different from those which were traveling without any vehicles in the adjacent lane. With 95% confidence, it was concluded that there was a statistically significant difference between the mean distances to the center-line of vehicles classified on the basis of vehicles in the adjacent lane. The results showed that there was an influence of the vehicles traveling in the adjacent lane on the lateral position of the vehicles in the target lane.

The platoon effect was also considered while reducing the data. Independent group t-tests were also applied for the individual categories of vehicles classified on the basis of platoon effect. The mean distances to the center-line of vehicles those affected by platoon was compared to the mean value of the distance to the similar kind of vehicles without platoon. The classification of the data on the basis of platoon is shown in Figure 5-6.

Figure 5-6 Ft. Riley Blvd. Data Classified on the Basis of Platoon



Independent group t-tests were applied for analyzing the data under the null hypothesis: There is no difference between the mean distances to the center-line of travel for the vehicles with platoon and those without platoon and the alternative hypothesis: The difference between the mean distances to the center-line of travel for the vehicles with platoon and those without platoon adjacent lane is statistically significant. The values obtained on applying the independent group t-tests are reported in Table 5-9.

Table 5-9 Details of the Independent Group t-test for the Data Classified on the Basis of Platoon

Details	Platoon	Size	Mean (Ft)	Std Dev. (Ft)	F-test		t-test	
					F-value	p-value	t-value	p-value
All vehicles	No	8,667	7.09	1.59	1.05	0.0380	2.85	0.0042
	Yes	5,383	7.01	1.63				
Passenger Cars	No	3,573	6.39	1.42	1.07	0.0640	2.02	0.0439
	Yes	2,305	6.31	1.47				
Vans	No	2,485	7.43	1.48	1.03	0.4587	**0.71**	**0.4766**
	Yes	1,570	7.40	1.51				
Pickups	No	2,083	7.57	1.46	1.05	0.3289	**1.07**	**0.2862**
	Yes	1,269	7.52	1.50				
Heavy Vehicles	No	526	8.43	1.60	1.00	0.9951	**-1.79**	**0.0732**
	Yes	239	8.65	1.60				

For the entire dataset (all vehicles) and the passenger cars, $p<0.05$, and hence, the alternative hypothesis was accepted. With 95% confidence, it was concluded that there was a statistically significant difference between the mean distance to the center-line of travel of the vehicles (all vehicles and passenger cars) tested with and without platoon effect.

For the other vehicles, vans, pickups and heavy vehicles it was inferred from the results that the mean distance to the center-line of travel of the vehicles with platoon was same as that of the vehicles without platoon. The p-values of the independent group t-tests applied for these vehicles were greater than 0.05, $p>0.05$. The null hypothesis was accepted and its alternative was rejected. With 95% confidence, it was concluded that there was no statistically significant difference between the mean distance to the center-line of travel of the vehicles (vans, pickups and heavy vehicles) tested with and without platoon effect.

The results from the platoon tests indicated that there may or may not be an influence of platoon on the lateral position of vehicles.

5.2 Before and After Study at Fort Riley Boulevard – Second Stage

The second stage of data analysis at the location of Ft. Riley Blvd. was performed to check for the impact of newly striped pavement markings along the section of the road on the drivers, thereby on the lateral position of the vehicles. The data was collected before and after the application of pavement markings at the test site. Data corresponding to 2,007 and 1,605 vehicles was reduced from the video tapes recorded as a part of the before and after study.

Independent group t-test was applied for data under the null hypothesis: Mean distance to the center-line of vehicles before the pavement markings is same as that of the vehicles after the pavement markings and the alternative hypothesis: The difference between the mean distance to the center-line of travel of vehicles before and after the application of pavement markings is statistically significant. The summary statistics of this study are reported in Table 5-10.

Table 5-10 Summary Statistics of the Before and After Study at Fort Riley Boulevard

Details	Condition	Size	Mean (Ft)	Std Dev. (Ft)	F-test		t-test	
					F-value	p-value	t-value	p-value
All vehicles	Before	2,007	8.69	0.84	1.11	0.021	1.96	0.0495
	After	1,605	8.63	0.85				

Very little difference was observed in the lateral position of the vehicles in the target lane due to the freshly striped pavement markings. The p-value from the independent group t-test indicated that the difference between the mean distance to the center-line of travel for the vehicles before and after the application of pavement markings were statistically significant. As $p<0.05$, the null hypothesis was rejected and its alternative was accepted. With 95% confidence, it was concluded that the difference between the means was statistically significant. It was concluded that better quality pavement markings may have an impact on the lateral position of the vehicles.

5.3 Vehicles Observed at Other Locations

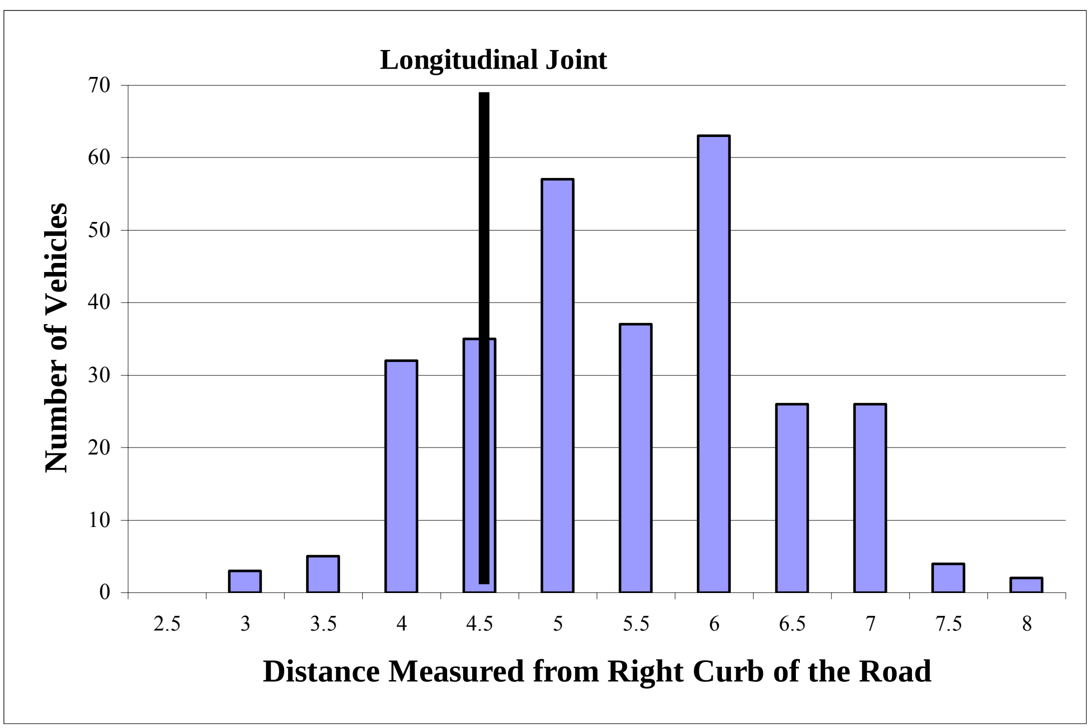
In addition to the data analysis carried out at the Ft. Riley Blvd. site, vehicles observed at other sites, MacVicar Avenue, K-4 Interchange and I-35/US-75 Interchange were also analyzed in this study. The details of the data analysis are discussed in the following sections.

5.3.1 Vehicles Observed at MacVicar Avenue, Topeka, Kansas

Data at MacVicar Avenue was collected in order to visualize where the drivers positioned their vehicles along the section of the road which had a clearly visible longitudinal joint, parallel to the roadway. Photographs of several vehicles traveling along the road were taken and the data analysis was carried out. The longitudinal construction joint was observed to be located at 4.50 ft. and the pavement striping was at 8.00 ft. from the right curb of the road.

The data corresponding to 329 vehicles of all types was analyzed. The distance was measured to the left lateral side of the vehicle from the right curb of the road. The wheel path of the vehicles along the width of the road was plotted by considering the number of vehicles as ordinate and the distance to the front right passenger side of the vehicle as abscissa, indicated in Figure 5-7.

Figure 5-7 Histogram of the Vehicles Observed at MacVicar Avenue

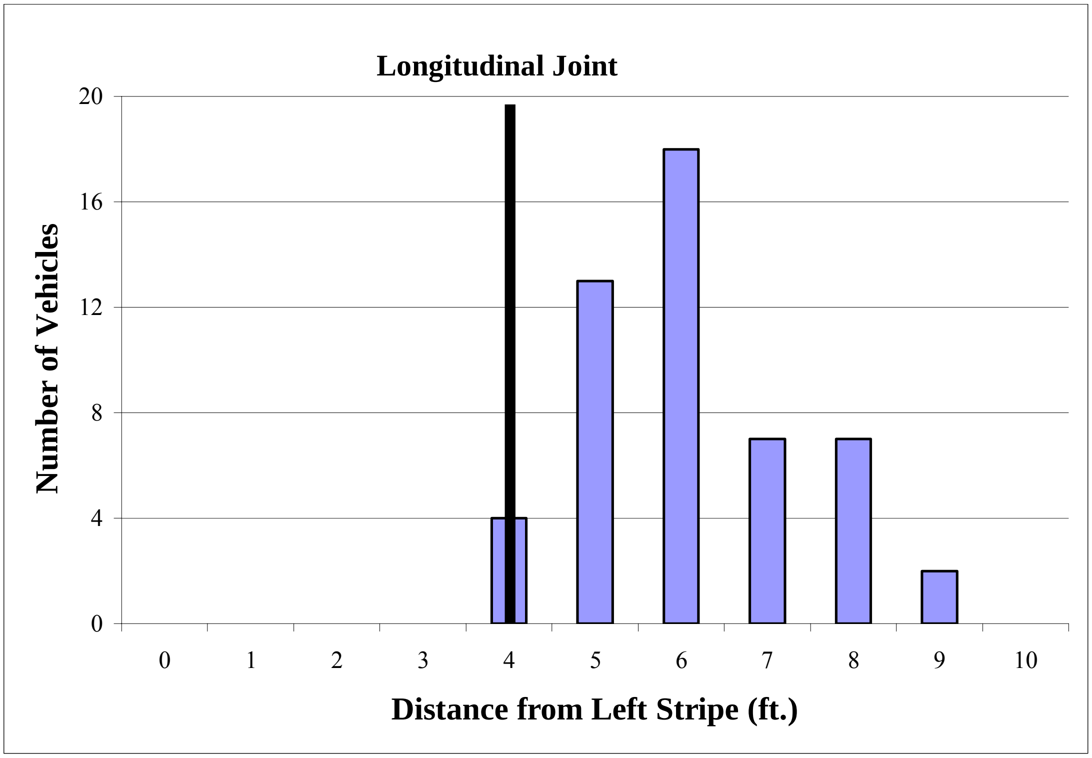


It was observed from the graph that the drivers of most of the vehicles positioned their vehicles in between 2.50 ft. and 6.00 ft. The longitudinal joint is marked on the graph by a solid continuous black line. The wheels of the vehicles were observed to straddle the joint, rather than traveling along the remaining part of the road. It was also found that some drivers positioned their vehicles with their left tires exactly over and away from the pavement striping marked on the road. Since the longitudinal joint was located at a different position, away from the pavement marking, there was a difference observed in the expected and the actual positioning of vehicles along the MacVicar Avenue.

5.3.2 Vehicles Observed at K-4 Interchange, Topeka, KS

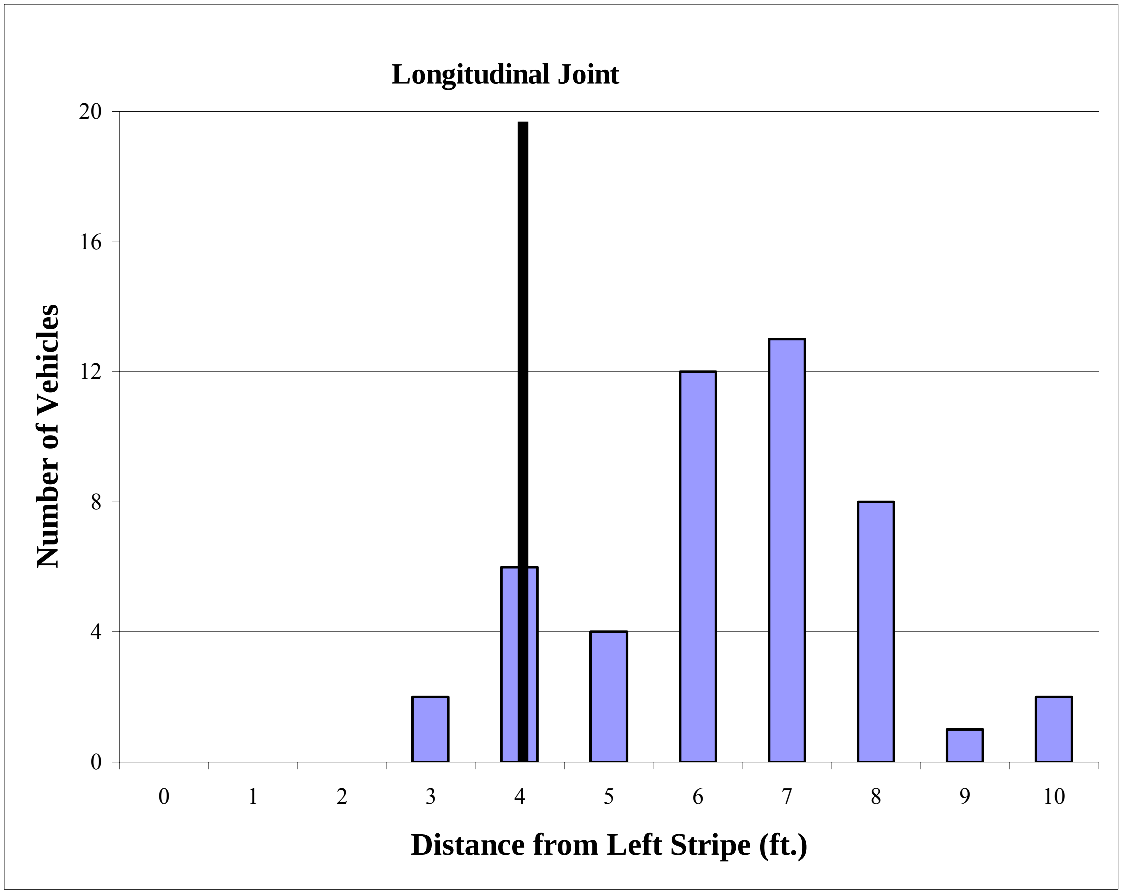
It was observed that the roadway at K-4 Interchange had a prominent longitudinal joint, located within the travel lane. The movements of the vehicles were captured during different times of the day. The total width of the ramp included a 14 ft. lane and a left and right shoulder. The width of the section of the roadway considered for analysis was measured as 10 ft. The longitudinal joint was located at 4 ft. away from the left stripe of the pavement. A total of 100 vehicles were recorded, under both the daytime and nighttime conditions. The graph in Figure 5-8 shows the distribution of the vehicles along the width of the roadway under daytime conditions.

Figure 5-8 Histogram of the Vehicles at K-4 Interchange – Daytime Observations



Under the daytime conditions, 51 vehicles were observed with a mean of 5.9 ft. and a standard deviation of 1.24 ft. The distance was measured from the left stripe to the right lateral side of the vehicle. 18 of the 51 vehicles were observed to be traveling at a distance to 6 ft. from the left stripe, which was as expected and 4 vehicles were seen positioned exactly over the joint. The data recorded during the daytime were compared to the nighttime observations. The distribution of vehicles at the K-4 Interchange during the nighttime conditions is shown in Figure 5-9.

Figure 5-9 Histogram of the Vehicles at K-4 Interchange – Nighttime Observations

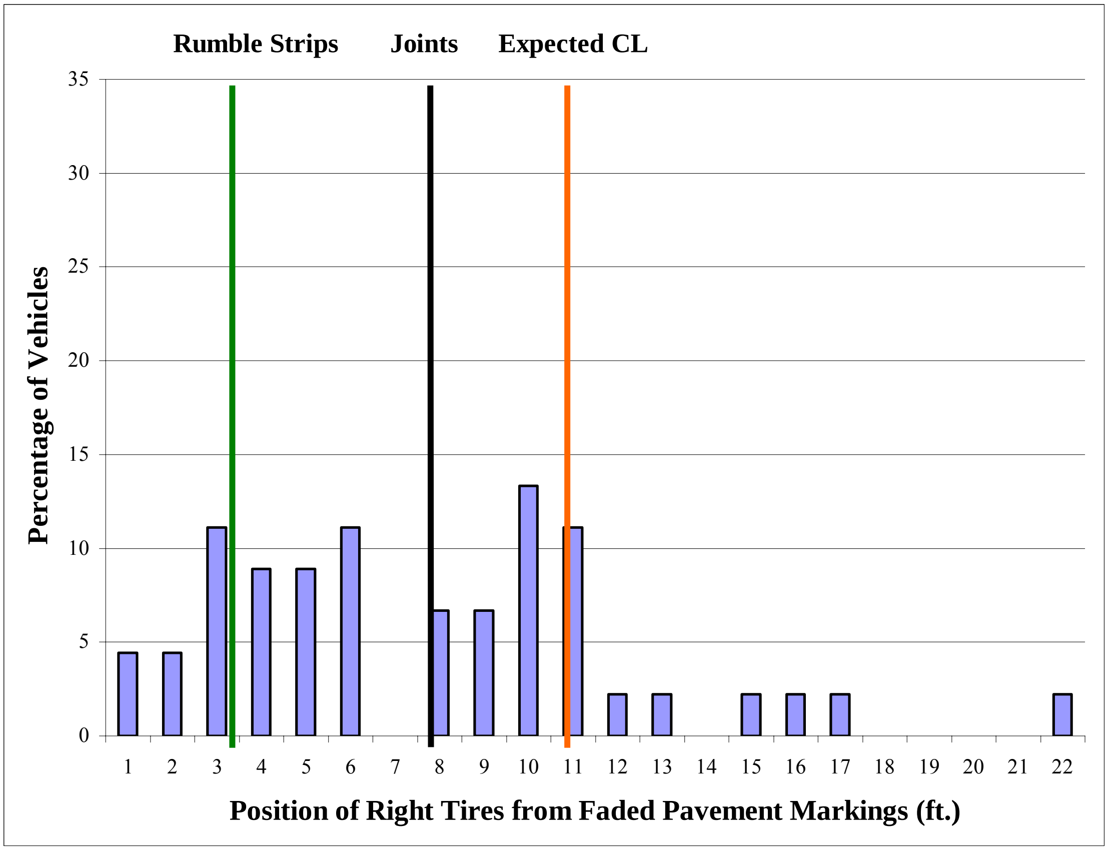


Under the nighttime conditions, 49 vehicles were observed, with a mean of 6.30 ft. and a standard deviation of 1.61 ft. The motorists of 12 vehicles positioned their vehicles at 6 ft. away from the left stripe of the road. 6 of the 49 vehicles were observed at 4 ft. away from the stripe, exactly over the joint, which was slightly higher than those under the daytime conditions. The analysis indicates that during the daytime, there may not be a significant impact due to the mismatch, but, under the nighttime, probably the drivers may be influenced by the mismatched longitudinal construction joints and pavement markings.

5.3.3 Vehicles Observed at I-35/US-75 Interchange, Topeka, KS

Photographs of 45 vehicles were captured and distance to the right tires of the vehicles under faded pavement markings were recorded under the before condition. Percentage of vehicles and distance to the right tires of the vehicles from faded pavement markings were the two variables considered for plotting the histogram, shown in Figure 5-10.

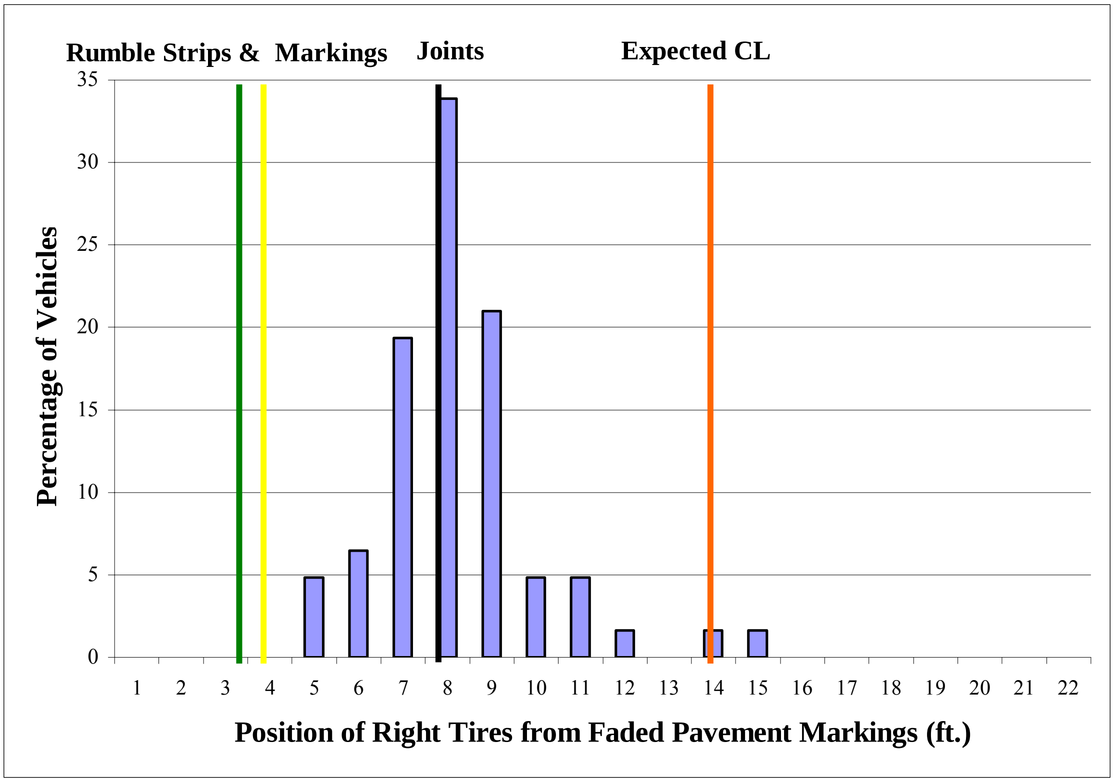
Figure 5-10 Histogram of the Vehicles at I-35/US-75 Interchange – Before Condition



The position of rumble strips, longitudinal joint and the expected center-line of vehicles under faded pavement markings are represented by green, black and orange lines in Figure 5-10. The distribution of vehicles at the I-35/US-75 Interchange recorded under before condition is shown in Figure 5-10.

Pavement markings were again laid on the I-35/US-75 Interchange, at a different position from the faded pavement markings. Data obtained from the photographs of vehicles traveling under the newly laid pavement markings was included as the after condition. The distribution of vehicles is shown in Figure 5-11.

Figure 5-11 Histogram of the Vehicles at I-35/US-75 Interchange – After Condition



It was observed that 34% of vehicles had right tires positioned exactly over the joints under the newly laid pavement markings. The life of pavement decreases due to the travel path of right tires of vehicles over the joints as excessive stresses are produced. Hence, it was found that upon the implementation of pavement markings, the lateral position of vehicles seemed to change. Therefore it can be concluded that the lateral position of vehicles may be affected by the unmatched longitudinal construction joints and pavement markings.

5.4 Linear Regression Model for Ft. Riley Blvd. data

The data was checked for normality and the results from the Anderson-Darling test indicated that the data satisfied the normal distribution. Forward selection, backward elimination and stepwise regression methods were applied in developing the linear regression model for predicting the dependent variable, "DISTANCE" from several independent variables. Information regarding the regression methods is discussed in section 5.4.

Forward Selection Process: One predictor variable is added at a time, and, there will not be further addition of variables when the remaining predictors fail to make a significant improvement in the model. The variable having the smallest p-value or the largest F-statistic is added first, followed by the remaining variables.

Backward Elimination Method: The variable of least importance is eliminated first, then on, the others which have largest p-values of smallest F-values are eliminated.

Stepwise Regression Method: Before adding another term, the stepwise method checks to see if a term already involved in a model is insignificant or not. If a term is found insignificant, it is dropped and the model continues.

The Analysis of Variance and Parameter estimates table obtained on applying various methods are reported in Table 5-11 and 5-12 respectively.

Table 5-11 Analysis of Variance Table for Regression Model

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	7230.31	1032.90	499.54	<0.0001
Error	14042	29035	2.07		
Corrected Total	14049	36265			

Root MSE	1.437	R-Square	0.1994
Dependent Mean	7.063	Adj. R-Sq	0.1990
Coeff Var	20.356		

The regression model has an F value of 499.54, and Pr>F, $p<0.00001$. The R-Square value of the model is 0.1994. Since $p<0.05$, it can be inferred that the independent variables reliably predict the dependent variable.

Table 5-12 Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > t	Type I SS	Type II SS
Intercept	1	8.06221	0.05687	141.76	<0.0001	701038	41554
weather	1	0.53901	0.02558	21.07	<0.0001	886.92870	918.31098
adjveh	1	-0.45593	0.04039	-11.29	<0.0001	259.18364	263.52101
dirn	1	0.27186	0.02509	10.84	<0.0001	232.07131	242.84433
platoon	1	-0.07159	0.02611	-2.74	0.0061	39.48386	15.54276
CA	1	-2.12986	0.05537	-38.47	<0.0001	5100.92277	3059.47717
VA	1	-1.04839	0.05684	-18.44	<0.0001	156.31334	703.38807
PU	1	-0.94515	0.05767	-16.39	<0.0001	555.40706	555.40706

The t-values of the independent variables and corresponding p-values can be obtained from Table 5-12. It can be inferred from the p-values that all the independent variables are significant in the model. The regression equation for predicting the independent variable "DISTANCE" from the other independent variables is shown in the Equation 11.

Equation 11 Regression Equation for Ft. Riley Blvd. Data for Predicting Distance

$$\begin{aligned}\text{distance} = 8.063 + 0.539\,\text{weather} - 0.456\ \text{adjveh} + 0.272\ \text{dirn} \\ - 0.072\,\text{platoon} - 2.129\,\text{CA} - 1.048\,\text{VA} - 0.945\,\text{PU}\end{aligned}$$

The dependent variable distance was expressed in terms of the independent variables, weather, vehicle in the adjacent lane (adjveh), movement (dirn), type of the vehicle (CA for passenger cars, VA for vans, PU for pickups), and, platoon. The value of R^2 was obtained as 0.1994. The significance of R^2 is that the greater its value, higher is the explanation of variation of the dependent variable by the independent variables. In spite of considering all the parameters observed while reducing the data, a smaller value of R^2 was obtained. The data considered was from the real-world and such a smaller value of R^2 made sense as we could predict the distance (dependent variable) from the other independent variables. The development of model was done in an academic point of view and helped in gaining an insight on the practical application of the observed data along with some conceptual orientation in statistics. The program code and other details are included in the Appendix E.

CHAPTER 6 - Summary Conclusions and Recommendations

The width of the target lane at the Fort Riley Boulevard was measured as 12.40 ft. If the vehicles are assumed to be guided by the pavement markings alone, mean distance to the center-line of travel of vehicles should have been 6.20 ft. which is half of the width of target lane. Results from statistical tests indicated that the mean distance to the center-line of travel for various types of vehicles was different from 6.20 ft.

Data collected at Ft. Riley Blvd. was classified on the basis of weather, movement, presence of vehicles in the adjacent lane, and platoon of vehicles. Most of the results were statistically significant, except for the heavy vehicles tested on the basis of movement, and vans, pickups and heavy vehicles tested for platoon. The test results indicated that the mean distances to the center-line of travel for various types of vehicles tested on the basis of several conditions were different from each other and were also different from 6.20 ft.

The results from the independent group t-tests applied for the data collected at Ft. Riley Blvd., and tested on the basis of vehicles in the adjacent lane were found to be statistically significant. From this, it may be concluded that the ambient traffic characteristics may have an effect on the lateral position of vehicles in the target lane.

Results from the before and after study conducted at Ft. Riley Blvd. indicated that there was a difference in the mean distances to the center-line of travel for the vehicles tested under faded and painted pavement markings under a level of significance of 0.05. However, the independent group t-test would have failed for higher levels of significance.

The longitudinal joints at the site at Ft. Riley Blvd. were located at 4.80 ft. and 13.80 ft. from the right curb of the road. There was a mismatch between the pavement markings and the joints. Since the pavement markings at the Ft. Riley Blvd. were not coincident with longitudinal construction joints, there may have been a possibility for the drivers to be guided by either of them, which may have resulted in difference in the mean distances to the center-line of travel of vehicles.

From the statistical tests conducted, it may be concluded that the unmatched longitudinal construction joints and pavement markings may have an effect on the lateral position of vehicles.

A linear regression model was also developed by considering the data reduced from the video tapes recorded during the first stage of data collection at Ft. Riley Blvd. The dependent variable, "DISTANCE" was predicted from the other independent variables. The R-square value was obtained as 0.1994. It implies that around 20% of variability in the dependent variable (DISTANCE) can be explained by the independent variables.

The data collection and analysis was limited only to one site as other sites with similar characteristics could not be obtained. The research can be extended by considering other sites with similar characteristics and collecting the data so as to make the findings more reliable.

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Appendix A - Specifications of Agencies on joints and markings

The construction specifications and standard specifications of all the departments of transportation within the United States were studied to check whether they had some provision on the positioning of longitudinal construction joints with respect to the pavement markings. The clause number and the specification of the corresponding transportation agency are included in Table A-1.

Table A-1 Construction Specifications Pertaining to the Positioning of Joints with Respect to the Markings

State	Agency	Specification
Alabama	Alabama Department of Transportation	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.
Alaska	Alaska Department of Transportation	Standard Specs 401-3.14 Joints: Align the joints in the top layer at the centerline or lane lines.
Arkansas	Arkansas Highway and Transportation Department	418.06 Construction Methods g) Workmanship: Longitudinal joints shall be placed at lane lines.

California	California Department of Transportation	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.
Colorado	Colorado Department of Transportation	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.
Delaware	Delaware Department of Transportation	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.
Florida	Florida Department of Transportation	709.4, 713.4 Offset longitudinal lines at least 2 inches from construction joints on portland cement concrete pavement.
Hawaii	State of Hawaii Department of Transportation	629.03 Do not install pavement markers over longitudinal or transverse joints of pavement surface, pavement making tape and thermoplastic extrusion markings.
Indiana	Indiana Department of Transportation	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.

Kansas	Kansas Department of Transportation	800/2200 Pavement Marking-Painting (d) Alignment: Normally locate longitudinal pavement marking stripes 50 mm.from existing longitudinal joints.
Kentucky	Kentucky Transportation Cabinet	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. 713.03 Construction: Offset longitudinal joints at least 2 inches from longitudinal pavement construction joints.
Louisiana	Louisiana Department of Transportation	732.03 d) Application of markings: Longitudinal lines shall be offset approximately 2 inches from the longitudinal joints.
Maine	Maine Department of Transportation	712.05 Application: Longitudinal lines shall be offset at least 50 mm [2 in] from construction joints of portland cement concrete pavement.
Maryland	Maryland Department of Transportation	Line and Grade Control (504) Joints in the top layer should be within 6 inches of the lane lines.
Massachusetts	Massachusetts Highway Department	466.63 Construction Requirements: 1.Application. Longitudinal joints shall be reasonably true to line and parallel to the centerline.
Michigan	Michigan Department of Transportation	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.

Minnesota	Minnesota Department of Transportation	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.
Mississippi	Mississippi Department of Transportation	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.
Nebraska	Nebraska Department of Roads	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.
Nevada	Nevada Department of Transportation	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.
New Hampshire	New Hampshire Highway Design	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).

New Jersey	New Jersey Department of Transportation	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.
New York	New York State Department of Transportation	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.
Oklahoma	Oklahoma Department of Transportation	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.
Oregon	Oregon Department of Transportation	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.

Rhode Island	Rhode Island Department of Transportation	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.
South Carolina	South Carolina Department of Transportation	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.
Tennessee	Tennessee Department of Transportation	Need to refer 414.07of their specifications.
Texas	Texas Department of Transportation	316.4 G Asphalt placement: Unless otherwise approved, match longitudinal joints with lane lines
Utah	Utah Department of Transportation	3.5 Surface Placement Place top course joint within one foot of the centerline or lane line.
Virginia	Virginia Department of Transportation	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.
Washington	Washington Department of Transportation	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.

West Virginia	West Virginia Department of Transportation	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.
Wisconsin	Wisconsin Department of Transportation	415.3.9.1 Joints: Parallel to the centerline along lane edges. On two lane pavements, construct them along the pavement centerline.
Wyoming	Wyoming Department of Transportation	409.4.4.1 Ensure that longitudinal joints coincide with the specified locations of lane lines, edge lines and center of traveled ways.

35 of the 50 departments of transportation had specifications concerning the positioning of longitudinal construction joints with respect to the pavement markings. 12 states did not have any information on the same, whereas the exact link to the standard specifications for 3 departments of transportation was not found.

Appendix B - Survey Details

Two surveys were conducted to solicit the opinions from the transportation professionals across the state and from throughout the country. The members from AASHTO responded to the first survey and those from KDOT to the second survey. The summary of their responses are discussed in Chapter three. This appendix includes the survey forms to give a general idea on the types of questions asked for obtaining the necessary information.

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.

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.

Appendix C - Program Code for One-Sample t-test Using SAS

Statistical Analysis Software (SAS) was used to perform the one-sample t-test for comparing the mean distance to the center-line of vehicles to a hypothetical value of 6.20 ft. (Half the width of the target lane). The program code and its output are as follows:

```
Data vikranth.ftrileyobs;
Input distance;
Datalines;
3.27
7.31
8.12
6.50
4.88
5.69
4.07
10.54
11.35
12.16
13.77
;
/* All the values considered for analysis are not included in the SAS code*/
Proc ttest data=vikranth.ftrileyobs H0=6.20;
Var distance;
Title 'Student's t-test for checking the mean distance to the center-line of vehicles';
Run;
```

Table C-1 One-Sample t-test for Checking the Mean Distance to the Center-Line of Vehicles

The t-test Procedure

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std. Dev.	Std. Dev.	Upper CL Std. Dev.	Std. Err.
Distance	14,050	7.04	7.06	7.10	1.59	1.61	1.63	0.014

t-tests

Variable	Degrees of freedom	t-value	Pr>t
Distance	14E3	63.72	<0.0001

The variable, ‘distance’ was considered for analyzing the data. A total number of 14,050 observations were used for performing the t-test. The t-test was conducted by assuming the null and alternative hypothesis.

Null Hypothesis: Mean distance to the center-line of vehicles is equal to 6.20

Alternative Hypothesis: The null is not true

Or

The mean value distance to the center-line of vehicles is different from 6.20

The p-value of the corresponding t-test is Pr>t is $p<0.0001$. Since the p-value is less than the α value (0.05), the t-test is said to be significant. It implies that the null hypothesis can be rejected and its alternative can be accepted. From this, it can be inferred that the mean distance to the center-line of vehicles is different from 6.20 ft.

Appendix D - Program Code for Independent Group t-test Using SAS

The group wise comparison for the data recorded at Fort Riley Boulevard was performed by using the independent group t-test. A program code was generated by using SAS. The code is as follows:

```
Data vikranth.fortrileygroup;
Input weather $ distance;
Datalines;
NW    3.27
AW    7.31
AW    8.12
NW    6.50
NW    4.88
AW    5.69
NW    4.07
AW    10.54
AW    11.35
AW    12.16
NW    13.77
;
/*Not all the values used for performing the t-test are shown in the SAS code.*/
Proc ttest cochran;
Class weather;
Var distance;
Title 'Independent group t-test for the data classified on the basis of weather conditions';
Run;
```

Table D-1 Independent Group t-test for the Data Classified on the Basis of Weather Conditions

The t-test Procedure

Variable	Weather	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std. Dev.	Std. Dev.	Upper CL Std. Dev.	Std. Err.
distance	adverse	5,532	6.718	6.755	6.791	1.347	1.372	1.398	0.0184
distance	normal	8,518	7.233	7.269	7.306	1.692	1.717	1.743	0.0186
diff.			-0.568	-0.515	-0.461	1.572	1.590	1.609	0.0275

t-tests

Variable	Method	Variances	Degrees of freedom	t-value	Pr>t
distance	Pooled	Equal	14E3	-18.74	<0.0001
distance	Satterthwaite	Unequal	13E3	-19.64	<0.0001
distance	Cochran	Unequal	…..	-19.64	0.0001

Equality of Variances

Variable	Method	Num DF	Den DF	F Value	Pr>F
Distance	Folded F	8517	5531	1.57	<0.0001

The mean value of the distance to the center-line of vehicles under normal weather conditions was compared to that of the vehicles traveling under adverse weather conditions. Independent group t-test was performed for the Ft. Riley Blvd. data by assuming the null and alternative hypothesis.

Null Hypothesis: The mean distances to the center-line of vehicles under normal weather conditions is equal to those traveling under adverse weather conditions.

Alternative Hypothesis: The mean distances to the center-line of vehicles under normal weather conditions is different from those traveling under adverse weather.

The t-statistic corresponding to either Satterthwaite or Cochran can be reported as the test values as the p-value corresponding to the Folded F-test is $p<0.0001$. As $p<0.05$.the t-value corresponding to any of the unequal variance tests can be reported as the test values. It was also observed that the p-value for the Satterthwaite and Cochran tests is $p<0.0001$. It can be inferred that the null hypothesis of the t-test can be rejected, and its alternative that the mean distances to the center-line of vehicles under normal weather conditions is different from those under adverse weather conditions can be accepted.

Appendix E - Program Code for Regression Model

The data collected during the first stage of the project, under obliterated pavement markings was used for predicting distance from the other parameters. The independent variables as mentioned earlier were identified as the types of vehicles, presence of a vehicle in the adjacent lane, weather condition, movement of the vehicle, and, platoon. A program code was generated by using SAS, which is as follows:

```
Data vikranth.regmodel;
Input vehicle $ adjveh weather dirn platoon distance;
Datalines;
P    1    0    0    1    6.50
H    0    0    0    0    8.79
T    1    1    0    1    5.49
V    1    0    0    0    11.26
H    0    0    1    0    13.50
;
/* Not all the values used for developing the regression model are included in the code*/
Data vikranth.regmodel;
Set vikranth.regmodel;
If vehicle = ‘P’ then CA=1; else CA=0;
If vehicle = ‘V’ then VA=1; else VA=0;
If vehicle = ‘T’ then PU=1; else PU=0;
Run;
Proc reg;
Model distance = adjveh weather dirn platoon CA VA PU/selection=forward;
Model distance = adjveh weather dirn platoon CA VA PU/selection=backward;
Model distance = adjveh weather dirn platoon CA VA PU/selection=stepwise;
Run;
```

The data considered for modeling was read by the input statement which included the variables: type of the vehicle, vehicle in the adjacent lane, weather condition, direction of travel, platoon and distance. The values of '0' and '1' correspond to the categorical variables. In this case, other than the distance, all the other variables considered were categorical variables. The presence of vehicle in the adjacent lane was assigned a value '1' else as '0'. If the weather condition was normal, it was coded as '1' else as '0' if it was adverse weather. The direction of travel was assigned as '1' if it was going straight. If it took a right turn, it was assigned '0'. The platoon of vehicles was also considered and they were similarly coded i.e. with platoon implies '1' and without platoon as '0'. For the type of the vehicle, if a passenger vehicle (P) was encountered, a new variable CA was defined, which took the value '1' else '0'. Likewise the other types of vehicles, vans and pickups were taken care of by defining new variables VA and PU. The other types of vehicles, heavy vehicle was not defined as the SAS code automatically generates a value '1' for this if it comes across 'H' as the type of the vehicle, else '0'. All the vehicles were thus coded in the model.

The in-built command proc reg in SAS was used for modeling the data using regression. The dependent variable was distance and the independent variables were adjveh, weather, dirn, platoon, CA, VA and PU. The model statement gives and idea on the variable to be estimated from the predictors. Forward selection, backward elimination and stepwise regression methods were used in modeling. The model statement in the proc reg contains several variables. To the left hand side, the variable which needs to be predicted (dependent variable) is defined. The right hand side includes all the predictors (independent variables). At the end of the model statement, the type of regression method can be specified by including the term, selection = forward, backward or stepwise.

The model resulted from all the three methods was the same i.e. the regression model yielded from forward selection, backward elimination and stepwise regression was one and the same. The R^2 value corresponding to all these methods was also the same. Hence, the regression equation was developed for Ft. Riley data by which, the distance could be predicted.

Forward selection, backward elimination and stepwise regression were used in predicting the distance whose details are discussed.

Forward selection method: Step wise description of the process is described.

Step I: Variable CA was added to the model and ANOVA table for model in first step:

Table E-1 Table for Step I of Forward Selection Method

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	5052.20302	5052.20302	2273.91	<0.0001
Error	14048	31213	2.22186		
Corrected Total	14049	36265			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	7.57228	0.01649	468578	210895	<0.0001
CA	-1.21564	0.02549	5052.29392	2273.91	<0.0001

Step II: In the second step, the variable “weather” was entered into the model.

Table E-2 Table for Step II of Forward Selection Method

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	5970.01901	2985.00951	1384.08	<0.0001
Error	14047	30295	2.15668		
Corrected Total	14049	36265			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	7.25670	0.02231	228072	105751	<0.0001
weather	0.52311	0.02536	917.72509	425.53	<0.0001
CA	-1.21937	0.02512	5083.09031	2356.90	<0.0001

Step III: In the third step, the variable adjveh was entered into the model.

Table E-3 Table for Step III of Forward Selection Method

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	6250.48148	2083.49383	975.02	<0.0001
Error	14046	30014	2.13687		
Corrected Total	14049	36265			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	7.29701	0.02249	224968	105279	<0.0001
weather	0.53785	0.02528	967.65890	452.84	<0.0001
adjveh	-0.46376	0.4048	280.46247	131.25	<0.0001
CA	-1.22197	0.02500	5104.36914	2388.72	<0.0001

Step IV: In the fourth step, the variable dirn was entered into the model.

Table E-4 Table for Step IV of Forward Selection Method

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	6489.96908	1622.49227	765.34	<0.0001
Error	14045	29775	2.11997		
Corrected Total	14049	36265			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	7.12838	0.02745	142967	67438.2	<0.0001
weather	0.54070	0.02518	977.80932	461.24	<0.0001
adjveh	-0.45971	0.04032	275.55519	129.98	<0.0001
dirn	0.26904	0.02531	239.48760	112.97	<0.0001
CA	-1.22286	0.02490	5111.78542	2411.26	<0.0001

Step V: In the fifth step, the variable VA was entered into the model.

Table E-5 Table for Step V of Forward Selection Method

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	6651.56722	1330.31344	630.90	<0. 0001
Error	14044	29613	2.10861		
Corrected Total	14049	36265			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	7.27511	0.03210	108312	52366.5	<0.0001
weather	0.52707	0.02516	925.56610	438.95	<0.0001
adjveh	-0.46678	0.04022	283.98512	134.68	<0.0001
dirn	0.27248	0.02525	245.58935	116.47	<0.0001
CA	-1.36270	0.02951	4490.33299	2129.52	<0.0001
VA	-0.28191	0.03220	161.59815	76.64	<0.0001

Step VI: In the sixth step, the variable PU was entered into the model.

Table E-6 Table for Step VI of Forward Selection Method

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	7214.76793	1202.46132	581.28	<0.0001
Error	14043	29050	2.06866		
Corrected Total	14049	36265			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	8.04985	0.05671	41688	20152.3	<0.0001
weather	0.52314	0.02492	911.74059	440.74	<0.0001
adjveh	-0.47421	0.03984	293.05907	141.67	<0.0001
dirn	0.27741	0.02501	254.53162	123.04	<0.0001
CA	-2.13737	0.05531	3088.62993	1493.06	<0.0001
VA	-1.05683	0.05677	716.86364	346.54	<0.0001
PU	-0.95109	0.05764	563.20070	272.25	<0.0001

Step VII: In the seventh step, the variable platoon was entered into the model.

Table E-7 Table for Step VII of Forward Step Method

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	7230.31069	1032.90153	499.54	<0.0001
Error	14042	29035	2.06770		
Corrected Total	14049	36265			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	8.06221	0.5687	41554	20096.6	<0.0001
weather	0.53901	0.02588	918.31098	444.12	<0.0001
Adjveh	-0.45593	0.04039	263.52101	127.45	<0.0001
Dirn	0.27186	0.02509	242.84433	117.45	<0.0001
Platoon	-0.07159	0.02611	15.54276	7.52	0.0061
CA	-2.12986	0.05537	3059.47717	1479.65	<0.0001
VA	-1.04839	0.05684	703.38807	340.18	<0.0001
PU	-0.94515	0.05767	555.40706	268.61	<0.0001

Upon entering all variables into the model, the dependent variable was expressed in terms of the independent variables as shown in the Equation 12.

Equation 12 Linear Regression Equation for Predicting Distance

$$\text{distance} = 8.063 + 0.539\,\text{weather} - 0.456\,\text{adjveh} + 0.272\,\text{dirn} - 0.072\,\text{platoon} - 2.129\,\text{CA} - 1.048\,\text{VA} - 0.945\,\text{PU}$$

The summary of the forward selection process is also obtained on selecting the method of regression as forward selection. It is as follows:

Table E-8 Summary of Forward Selection Process

Step	Variable Entered	Number Vars in	Partial R-Square	Model R-Square	C(p)	F Value	Pr>F
1	CA	1	0.1393	0.1393	1049.35	2273.91	<0.0001
2	weather	2	0.0253	0.1646	607.51	425.53	<0.0001
3	adjveh	3	0.0077	0.1724	473.88	131.25	<0.0001
4	dirn	4	0.0066	0.1790	360.05	112.97	<0.0001
5	VA	5	0.0045	0.1834	283.90	76.64	<0.0001
6	PU	6	0.0155	0.1989	13.52	272.25	<0.0001
7	platoon	7	0.0004	0.1994	8.00	7.52	0.0061

The R-square value after the entry of all the reliable independent variables was observed as 0.1994. It implies that approximately 20% of the variability in the dependent variable ‘distance’ can be explained by the other predictor variables.

Backward Elimination Method: The regression equation for prediction the distance was obtained in the first step itself. The ANOVA table and the corresponding parameter estimates table, along with the regression equation were same as that of the output obtained from the forward selection process.

Stepwise Regression Method: For this method too, the regression equation and other values were similar to those obtained from the forward selection process.