EVALUATION OF THE FEASIBILITY OF POSTING REDUCED SPEED LIMITS ON KANSAS GAVEL ROADS

by

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Abstract

In the United States, the mileage of unpaved roads is about 1.6 million miles. Total length of unpaved roads in Kansas is about 98,000 miles, of which about 78,000 miles are gravel roads. Most of the gravel roads are not posted with speed limit signs but regulated with a 55 mph blanket speed limit established by the Kansas Statutes. Surface conditions of gravel roads are very likely to change with time, space, and quality of maintenance work, making it even more necessary to have proper control of speeds on gravel roads. Normally used speed regulations and rules for freeways or other types of paved roadways might not be appropriate for gravel roads, especially for those local gravel roads which usually carry very low traffic in rural areas. Based on an extensive literature search, there was no specific rule or references to provide guidelines on how speed limits on gravel roads could be set. Therefore, an effort was made in this study to evaluate the effects of currently posted lower speed limits in some counties in Kansas, based on traffic characteristics and safety on gravel roads, with the intention of providing proper guidelines for setting speed limits on gravel roads in Kansas.

In order to study traffic characteristics on gravel roads, field speed studies were conducted with automatic traffic counters on more than forty gravel road sections in seven counties in Kansas. Important speed measures, such as 85th-percentile speed and mean speed, were obtained from the raw data. A group of other related road characteristics were also recorded at the time of field data collection. Crash data on gravel roads were extracted from the Kansas Accident Recording System (KARS) database.

Speed analysis on a number of gravel roads where the statutory imposed, unposted speed limit of 55 mph was utilized indicated that they are functioning at a reasonably acceptable level in terms of actual speeds. In order to evaluate whether there were differences in traffic speeds between two counties or groups which have different speed limit settings on gravel roads, t-test was used. The analysis found that there was no significant difference between the mean speeds in two counties, one of which has 35 mph posted speed limit on gravel roads while the other does not post any speed limits. Moreover, the mean speed on the sections with 35 mph posted speed was a little higher than that on gravel roads without any speed limits. Linear models to predict 85th-percentile speed and mean speed on gravel roads were developed based on speed data. Both models indicated that traffic speeds are not significantly affected by the speed limit, but are

related with 90% confidence to road width, surface classification and percentage of large vehicles in traffic. Chi-square tests were conducted with the crash data, and the results indicated that the posted 35 mph speed limit on gravel roads had not resulted in either smaller total number of crashes or decreased proportion of severe crashes, compared to gravel roads where no speed limits were posted. Logistic regression models were also developed on four levels of crash severity, which indicated that gravel roads with higher speed limits are likely to experience higher probability of having injury crashes.

Two mail-back surveys were also conducted to gather the opinions of county engineers and road users on the subject of suitable speed limits on gravel roads. The majority of county engineers believed that blanket speed limit should be used for gravel roads and does not need to be posted. Three restrictions: changeful road conditions, unpractical law enforcement, and limited funds, are basic reasons why they do not think that gravel roads should be posted. Besides that, a few respondents said 55 mph is too high for gravel roads and needs to be lowered. Majority of the road users suggested that all gravel roads be posted with lower speed limit signs. However, they were more concerned about law enforcement since they believe that posted speeds won't bring any benefits if no law enforcement patrol gravel roads.

Based on all aspects looked into in this study, it does not appear that reducing the speed limits and posting it with signs, is going to improve either traffic operational or safety characteristics on gravel roads in Kansas, and therefore is not recommended for new situations.

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Dedication

I would like to sincerely dedicate my thesis to my wife, Hong Shan, and my daughter, Catherine Y., Liu. They have been a driving impetus pushing me forward. I would also dedicate this work to my mother, Shufen Fang, and my father, Jingquan Liu. This thesis is also dedicated to my brothers Lixin and Lijun, my sister-in-law Libo Shan and her family. Without the support, patience, understanding, and most of all love from my family members, the completion of this work would not have been possible.

CHAPTER 1 - Introduction

1.1 Background

In Kansas, the total mileage of unpaved roads is over 98,000 miles which is about 72.5% of the total road mileage and carries about 10% of the annual vehicle miles travelled (FHWA, 2005). The total length of gravel roads is about 77,900 miles which is 57.6% of the total road mileage in Kansas. Table 1.1 shows the mileages of unpaved roads based on functional class from 1996 to 2005, which is the sum of total length of both gravel roads and dirt roads that are unimproved county roads. Out of total unpaved road mileage, rural unpaved roads account for about 99% of the total length and urban roads occupy only 1%.

Table 1.1 Mileage of Unpaved Roads in Kansas from 1996 to 2005

Year	Rural (miles)				Urban (miles)				Total
	Major Collector	Minor Collector	Local	Subtotal	Minor Arterial	Collector	Local	Subtotal	
1996	11,717	8,483	77,856	98,056	14	38	728	780	98,836
1997	11,791	8,478	77,864	98,133	13	40	727	780	98,913
1998	11,815	8,480	77,862	98,157	14	43	727	784	98,941
1999	12,202	8,430	77,953	98,585	13	114	730	857	99,442
2000	12,525	8,457	78,428	99,410	13	37	700	750	100,160
2001	12,037	8,457	78,362	98,856	13	37	700	750	99,606
2002	10,460	8,460	78,584	97,504	5	57	710	772	98,276
2003	10,240	8,446	78,562	97,248	5	46	736	787	98,035
2004	10,293	8,454	78,576	97,323	2	49	775	826	98,149
2005	10,441	8,479	78,226	97,146	72	113	875	1,060	98,206

Source: Federal Highway Administration (FHWA), 1996-2005.

The mileage of unpaved roads is plotted in Figure 1.1, which indicates that the total mileage reached the highest point in 2000, then fell through 2003 and kept at the same level to 2005. The length urban gravel roads has been at the same level from 1996 to 2004 and increased by 27% in 2005.

Figure 1.1 Unpaved Roads Mileages in Kansas from 1996 to 2005

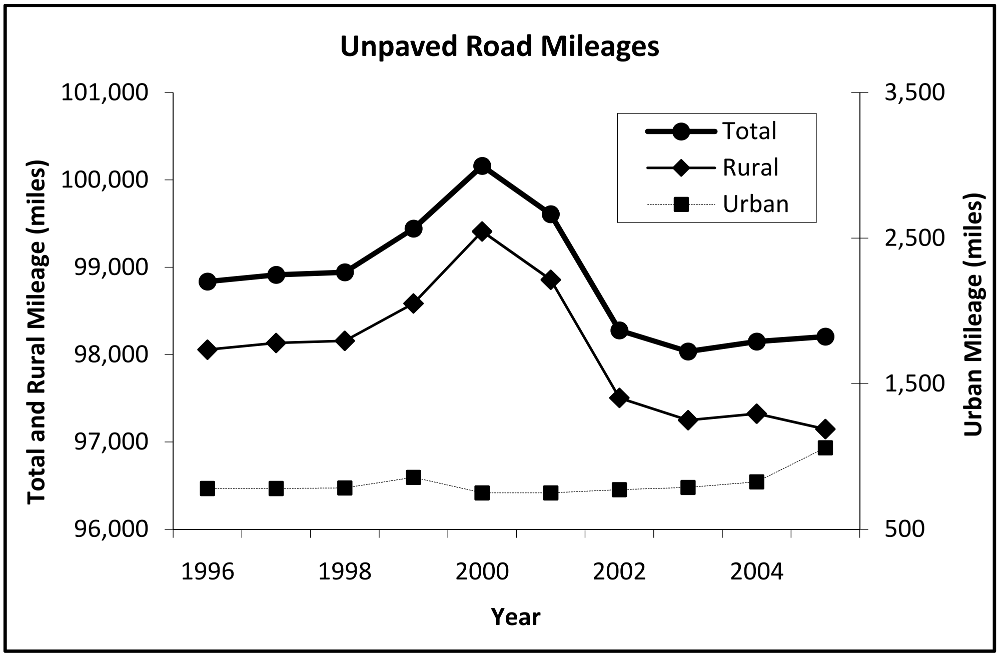


Table 1.2 is a summary of gravel road mileages and the corresponding percentages of total road network in each county of Kansas. As shown in Table 1.2, gravel roads account for more than a half the length of total roads in the majority of these counties. Wyandotte County is an exception, which has no gravel roads.

During the period of 1996 to 2005, a total of 433 fatal crashes were reported on Kansas gravel roads and resulted in 478 personal fatalities which accounted for about 10% of the total number of fatalities due to motor vehicle crashes in Kansas (KDOT, 2006). That was six times higher than the corresponding national percentage which was about 1.4% (NHTSA/USDOT, 2007). The figures indicate that traffic safety on Kansas gravel roads is a problem of considerable magnitude though they carry relatively small part of the total traffic volume.

Table 1.2 County Gravel Road Mileages in Kansas (2007)

County	Gravel (miles)	Total (miles)	Percent		County	Gravel (miles)	Total (miles)	Percent
Allen	840	1,087	77.3%		Linn	750	1,187	63.2%
Anderson	900	1,102	81.7%		Logan	215	946	22.7%
Atchison	425	906	46.9%		Lyon	1,048	1,680	62.4%
Barber	400	1,009	39.6%		Marion	804	1,833	43.9%
Barton	500	1,875	26.7%		Marshall	700	1,660	42.2%
Bourbon	825	1,207	68.4%		McPherson	1,083	1,815	59.7%
Brown	570	1,211	47.1%		Meade	750	1,014	74.0%
Butler	2,050	2,497	82.1%		Miami	700	1,216	57.6%
Chase	475	631	75.3%		Mitchell	458	1,276	35.9%
Chautauqua	650	728	89.3%		Montgomery	850	1,475	57.6%
Cherokee	801	1,274	62.9%		Morris	900	1,098	82.0%
Cheyenne	671	1,210	55.5%		Morton	367	967	38.0%
Clark	-	759	-		Nemaha	528	1,424	37.1%
Clay	590	1,210	48.8%		Neosho	900	1,239	72.6%
Cloud	504	1,365	36.9%		Ness	1,019	1,386	73.5%
Coffey	962	1,231	78.1%		Norton	700	1,356	51.6%
Comanche	578	688	84.0%		Osage	916	1,366	67.1%
Cowley	1,200	1,805	66.5%		Osborne	230	1,260	18.3%
Crawford	888	1,398	63.5%		Ottawa	587	1,213	48.4%
Decatur	450	1,237	36.4%		Pawnee	827	1,405	58.9%
Dickinson	557	1,737	32.1%		Phillips	619	1,487	41.6%
Doniphan	394	718	54.9%		Pottawatomie	820	1,337	61.3%
Douglas	571	1,221	46.8%		Pratt	1,262	1,333	94.7%
Edwards	665	1,019	65.3%		Rawlins	900	1,257	71.6%
Elk	734	787	93.3%		Reno	685	2,732	25.1%
Ellis	1,192	1,510	78.9%		Republic	700	1,413	49.5%
Ellsworth	700	1,159	60.4%		Rice	1,036	1,397	74.2%
Finney	1,100	1,496	73.5%		Riley	406	918	44.2%
Ford	1,041	1,748	59.6%		Rooks	500	1,466	34.1%
Franklin	900	1,197	75.2%		Rush	728	1,312	55.5%
Geary	223	613	36.4%		Russell	1,118	1,425	78.5%
Gove	1,100	1,163	94.6%		Saline	721	1,458	49.5%
Graham	300	1,240	24.2%		Scott	666	804	82.8%
Grant	528	807	65.5%		Sedgwick	857	3,969	21.6%
Gray	1,174	1,269	92.5%		Seward	580	905	64.1%
Greeley	600	678	88.5%		Shawnee	760	1,814	41.9%
Greenwood	1,281	1,437	89.1%		Sheridan	790	1,345	58.7%
Hamilton	-	734	-		Sherman	1,052	1,232	85.4%
Harper	1,000	1,417	70.6%		Smith	750	1,540	48.7%
Harvey	822	1,244	66.1%		Stafford	1,352	1,448	93.4%
Haskell	500	830	60.2%		Stanton	539	732	73.6%
Hodgeman	-	1,067	-		Stevens	784	1,064	73.7%
Jackson	734	1,223	60.0%		Sumner	1,125	2,365	47.6%
Jefferson	663	1,111	59.7%		Thomas	114	1,472	7.7%
Jewell	498	1,649	30.2%		Trego	800	1,215	65.8%
Johnson	234	2,926	8.0%		Wabaunsee	700	1,018	68.8%
Kearny	650	818	79.5%		Wallace	530	723	73.3%
Kingman	1,105	1,465	75.4%		Washington	976	1,691	57.7%
Kiowa	697	864	80.7%		Wichita	675	826	81.7%
Labette	971	1,340	72.5%		Wilson	752	1,085	69.3%
Lane	430	720	59.7%		Woodson	758	845	89.7%
Leavenworth	456	1,004	45.4%		Wyandotte	0	1,089	0%
Lincoln	563	1,147	49.1%		Grand Total	77,900	135,321	57.6%

“-” denotes that data provided by these counties are not reliable.
Source: Joint data from county survey, county annual report, county highway map and *Selected Statistics*.

1.2 Problem Statement

As widely accepted, speed limits play a very import role in improving traffic operations and transportation safety, making it necessary to set speed limit properly on gravel roads. Accordingly, this research focuses on the speed limit related issues on gravel roads, which was originated by county engineers who had concerns about whether or not current regulatory speed limit is appropriate for existing conditions and whether speed signs should be posted on gravel roads.

The Kansas Statutes has regulated 55 mph as the maximum speed limit on county and township highways including gravel roads. The law also empowers local governments the authority to increase and decrease the proper speed limits on county or township highways within their jurisdictions with or without an engineering and traffic investigation, but no speed limit higher than of 65 mph is permitted under any circumstances (Kansas Legislature, 2006). Based on that, a few counties have reduced the speed limit to other values like 45 mph or 35 mph and posted the speed limit signs on all gravel roads within their jurisdictions. However, the rest counties apply the 55mph statutory speed limit which is not normally posted on gravel roads.

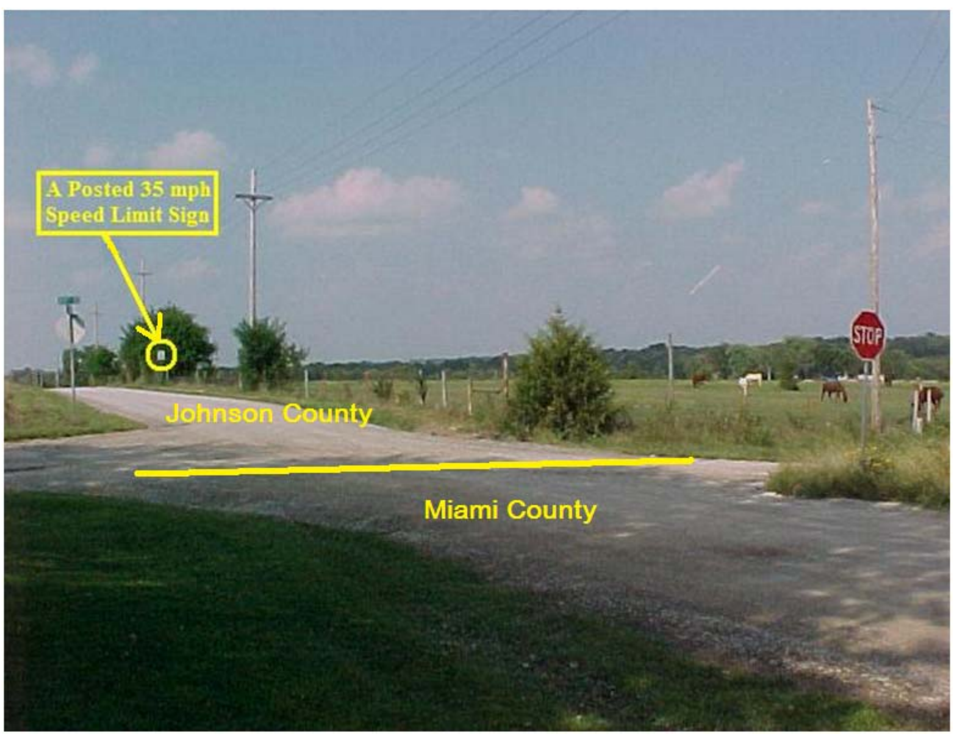
Two counties in Kansas, Johnson and Smith Counties, have been found to be using posted speed limits on all gravel roads within their jurisdictions. Figure 1.2 shows a gravel road in Johnson County, which is posted with 35 mph speed limits signs on the right side. This kind of signs can be observed on gravel roads throughout this county. 45 mph speed limit signs are posted on all gravel roads in Smith County.

Figure 1.3 shows an intersection of two gravel roads at the boundary between Johnson and Miami Counties. The highlighted area of this picture is a posted 35 mph sign in the section on Johnson County, while no speed limit signs could be found in the section on Miami County.

The different speed limit setting criteria on different counties, especially between two adjoining counties might be a problem for road users to follow the regulations. It is necessary to find out whether the posted speed limits really have an impact on traffic speeds and are helpful with improving traffic operation safety on gravel roads. If posted speed limits are verified to be very useful, the feasibility of posting reduced speed limits on all gravel roads needs to be evaluated. Therefore, this research has been proposed to address speed limit related issues with respect to gravel roads.

Figure 1.2 The W127th St. in Johnson County with a Posted 35 mph Sign

Figure 1.3 An Intersection at the Boundary between Johnson and Miami Counties



1.3 Objectives

The primary objective of this study is to evaluate the association of speed limit with traffic operation characteristics as indicated by actual speeds and safety situation on gravel roads. This study also attempts to develop appropriate models to be able to predict important speed measures and estimate potential crash risks on gravel roads under given characteristics. Based on the evaluations, suggestions can be made on whether the 55 mph statutory speed limit is appropriate for existing conditions of gravel roads or whether gravel roads should be posted with reduced speed limits.

1.4 Organization of the Thesis

This thesis consists of seven chapters and three appendices. Chapter 1 presents the background information and the objectives of this study. Chapter 2 provides a summary of the literature review based on relevant references related to gravel road. Chapter 3 describes the details of the collection of both speed data and crash data on Kansas gravel roads. Chapter 4 introduces the statistical methodologies used to analyze the data and the method for conducting surveys. Chapter 5 presents the results and findings of the statistical analyses of this study based on speed and crash data. Chapter 6 summarizes the results of two sets of surveys. The summary, conclusions and recommendations of this project are presented in Chapter 7. The appendices consist of the samples of survey forms used in this study to understand the characteristics associated with speed limit on gravel roads in Kansas. A summary of typical comments from county engineers is also provided in the appendices.

CHAPTER 2 - Literature Review

An extensive literature review is presented in this chapter with respect to basic characteristics of gravel roads and related studies. Most of previous speed limit studies were focused on urban arterials and rural highways that carry heavy traffic volumes or are prone to have high possibility of accidents. A small number of studies were found to focus on the speed limits on low volume rural roads. Fewer studies could be found addressing speed limits related issues on gravel roads. Therefore, some general literatures are included in this chapter to provide a good understanding of gravel roads.

2.1 Functional Class

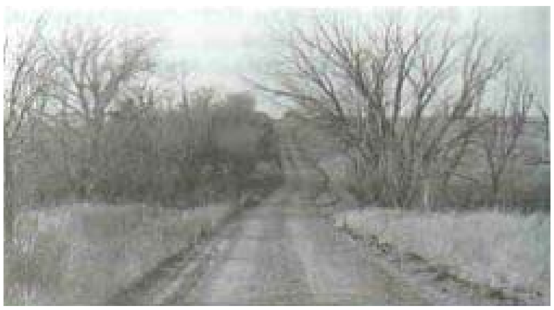
Unpaved roads are generally appropriate for all functional subclasses of very low-volume local roads, which primarily provide access to land adjacent to the collector network and serves travel over relatively short distances. Provision of an unpaved surface is an economic decision that is appropriate for many very low-volume local roads for which the cost of constructing and maintaining a paved surface would be prohibitive (AASHTO, 2001).

In Kansas, the classification and corresponding physical characteristics of low-volume roads (LVR) have been studied, and three types labeled as A, B and C, were classified accordingly (Russell and Smith, 1995). Figure 2.1 shows typical examples of each type. The example for type A is an aggregate-surfaced rural road. Type B and C are usually nature-surfaced or primitive roads. Table 2.1 summarizes the typical characteristics of each type of LVR roads. It has been commented that drivers are likely to have higher expectancy on the maintenance and signage on higher class roads and drive at higher speed with less caution, and show lower expectancy on primitive roads (Russell and Smith, 1995).

Figure 2.1 Typical Types A, B and C Low-Volume Roads in Kansas

Type A

Type B



Type C

Type C (primitive road)

(Source: Russell and Smith, 1995)

Table 2.1 Typical Characteristics of Low-Volume Road by Classification

Characteristics	Road Type		
	Type A	Type B	Type C
Typical Width of Traveled Way and number of visible wheel paths	22′ or greater, 3 or 4 visible wheel paths (if gravel)	16′-24′, 2 or 3 visible wheel paths	2 or no visible wheel paths
Prudent Operating Speed	40 mph or greater	25-45 mph	40 mph or less
Surface Material	paved or aggregate	aggregate	natural surface may have some aggregate
Riding Quality	no adverse effect	may cause reduction in operating speed	typically poor, may be impassable due to poor weather
Drainage	All-weather road- good surface drainage; water carried to ditches	All-weather road- some surface ponding; water carried in ditches	Fair-weather road- ditches are narrow or nonexistent; surface ponding likely to affect drivability

(Source: Russell and Smith, 1995)

Table 2.2 describes the suggested driver expectancies for each type of LVR. Based on knowledge of what drivers expect for LVRs, appropriate actions can be taken to lessen or remedy inconsistencies on LVRs (Russell and Smith, 1995).

Table 2.2 Driver Expectancies for Each Roadway Type of LVR

Conditions	Road Type		
	Type A	Type B	Type C
Roadside Obstacles/ Vertical Alignment	Some/ consistent with previous ½ to 1 mile	Some/ consistent with previous ½ to 1 mile	Many/ may be consistent with previous ½ to 1 mile
Horizontal Alignment	consistent with previous ½ to 1 mile	consistent with previous ½ to 1 mile	consistent with previous ½ to 1 mile
Vehicle Right of Way at Intersection	expects to have right of way	prepared to yield right of way	expects to yield right of way
Safe Stopping Sight Distance	adequate for usual operating speed	adequate for usual operating speed	adequate for usual operating speed
Influence of Opposing Traffic	none	slow down to pass opposing vehicle	difficult to pass opposing vehicle

(Source: Russell and Smith, 1995)

2.2 Geometric Characteristics

Geometric design guidelines for local rural roads are provided in the "A Policy on Geometric Design of Highways and Streets" (also known as Green Book) which was published by the American Association of State Highway and Transportation Officials (AASHTO). These guidelines can be applied in the design and maintenance of gravel roads as well.

As shown in Table 2.3, minimum design speed for local rural roads varies in the range of 20 mph to 50 mph based on terrain type and design traffic volume (AASHTO, 2001). For a gravel road with an ADT less than 250 vehicles per day, a 30 mph design speed shall be satisfied.

Table 2.3 Minimum Design Speed for Local Rural Roads

Type of Terrain	Design Speed (mph) based on Design Volume (vehicle/day)					
	< 50	50 - 250	250 - 400	400 - 1,500	1,500 - 2,000	> 2000
Level	30	30	40	50	50	50
Rolling	20	30	30	40	40	40
Mountainous	20	20	20	30	30	30

(Source: AASHTO *Green Book*, 2001)

Table 2.4 shows the design stopping sight distance for different initial speeds at different rates of vertical curvatures (AASHTO, 2001).

Table 2.4 Design Stopping Sight Distance for Vertical Curves on Local Rural Roads

Initial Speed (mph)	Design Stopping Sight Distance (ft)	Rate of vertical curvature, K* (ft%)	
		Crest Curves	Sag Curves
15	80	3	10
20	115	7	17
25	155	12	26
30	200	19	37
35	250	29	49
40	305	44	64
45	360	61	79
50	425	84	96
55	495	114	115
60	570	151	136

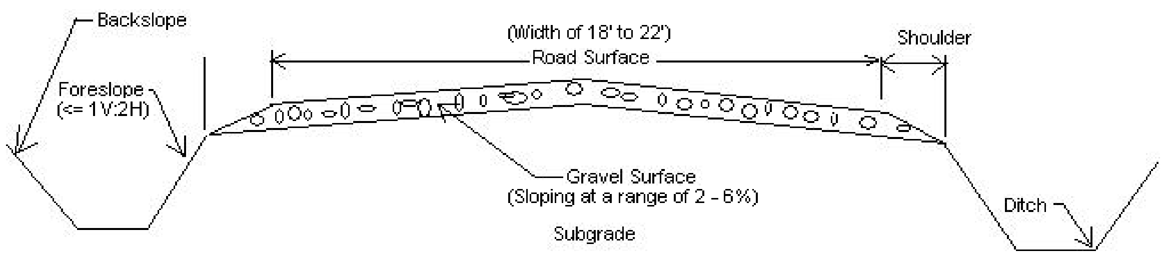
* K is the rate of vertical curvature, denoting the length of curve per percent algebraic difference in the intersecting grades, i.e. K = L/A, where L = Length of vertical curve and A = Algebraic difference in grade.

(Source: AASHTO *Green Book*, 2001)

The typical cross-section of a gravel roadway is shown in Figure 2.2. A well designed gravel road has a traveled roadway with a width varying from 18 to 22 ft, gravel surface at 2-6% slope, shoulders, and ditches on both roadsides (AASHTO, 2001). At underpasses, a minimum

14 ft vertical clearance over the entire roadway width is required with an allowance for future resurfacing work.

Figure 2.2 Typical Cross-Section of Gravel Road



Intersections should be carefully located and designed to avoid steep profiles and provide adequate sight distance. An intersection should not be situated just beyond a short-crest vertical curve or on a sharp horizontal curve. When this situation cannot be avoided, the approach sight distance on each leg of the intersection should be checked, backslopes should be flattened, horizontal and vertical curves should be lengthened to provide additional sight distance at where practical. For stop controlled intersections, the legs of two directions should intersect at right angles wherever practical, and should not intersect at an angle less than 60 degrees (AASHTO, 2001).

2.3 Surfacing Materials

A good gravel surface consists of three elements: gravel, sand, and fines (clay and silt). A good blend has a mixture of all three sizes (i.e. 40%-80% hard stone, 20%-60% sand and 8%-15% fines of total weight). There are several types of gravel which can be used for grading gravel roads, including pit-run gravel, screened gravel, washed gravel and crushed gravel. Pit-run and screened gravel are taken out of a natural deposit, very often from an old stream bed. Washed gravel is gravel in which excess fines are removed by water. Crashed gravel or rocks are used where good quality natural gravel is not available (Kentucky Transportation Center, 1987).

The coefficient of friction on gravel surfaces varies at a range from 0.40 to 0.70, which is much lower than that on paved surfaces and is shown in Table 2.5 (Fricke, 1990). The coefficient of friction is used to calculate the stop distance for a given initial speed (i.e., $d = 1.47Vt + 1.075V^2/a$ in ASSHTO Green Book). Stopping distance has an inverse relationship with coefficient of friction. Therefore, longer stopping distance is usually needed than on asphalt pavement under similar other conditions.

Table 2.5 Coefficients of Friction on Different Surfaces

Surface type	Coefficient of friction
Concrete pavement –dry	0.60 to .75
Concrete pavement – wet	0.45 to .65
Asphalt pavement	0.55 to .70
Gravel	**0.40 to .70**
Ice	0.05 to .20
Snow	0.30 to .60

(Source: Fricke, 1990)

2.4 Speed regulations

This section presents the literature with regard to speed regulations on gravel roads, including definitions, signs, state speed laws, and related speed limit studies.

2.4.1 Definitions of Speed Limit

According to the Institute of Transportation Engineers (ITE), all states formulate their speed regulations on the basis of the basic speed law, which specifies that a driver shall operate a vehicle at a speed that is reasonable and prudent for existing conditions, regardless of any other speed limit that may be applicable at a location at any given time (ITE, 1999). The ITE defines the basic concepts of speed limit as follows (ITE, 1999):

- *Statutory Speed Limit*: “an absolute limit above which it is unlawful to drive regardless of roadway conditions, amount of traffic, or other influential factors”
- *Prima Facie Speed Limit:* “a limit above which drivers are presumed to be driving unlawfully, while driver may contend that their speed was safe for existing conditions at that time when charged with a violation of this prima facie limit”
- *Speed Zone*: “a safe and reasonable limit on the basis of a traffic engineering investigation and may modify the basic speed limit by law or ordinance”

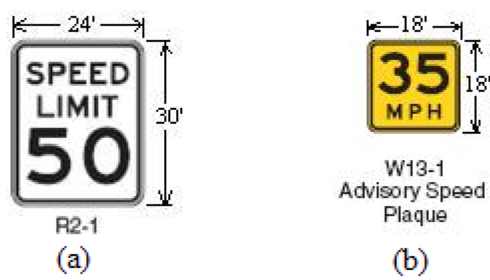
Speed zones consist of two types (ITE, 1999):

a) Enforceable as absolute or prima facie limits on the basis of regulatory speed limits, and
b) Advisory maximum speed indications which are not enforceable but advice or warn motorists of safe speeds for specific conditions.

2.4.2 Speed Signs for Low-Volume Roads

The low-volume roads should be classified as either paved or unpaved (FHWA, 2003). As per the Manual on Uniform Traffic Control Devices (MUTCD), speed limit signs (coded as R2-1) need to be used on low-volume roads where limits are necessary with a typical sign size of 24'×30' as shown in Figure 2.3 (a), and the minimum sign size 18'×24' can only be posted where the 85th-percentile speed or posted speed limit is less than 35 mph (60km/h) (FHWA, 2003). Appropriate locations where speed limit signs are needed are suggested as those roads that carry traffic from, onto, or adjacent to higher-volume roads that have posted speed limits. An advisory speed plaque (W13-1), as shown in Figure 2.3 (b), may be mounted below a warning sign when the conditions require a reduced speed (FHWA, 2003).

Figure 2.3 Regulatory and Advisory Speed Limit Signs



2.4.3 State Speed Limit Laws

Speed regulations vary among the 50 states with regard to roads with different surfaces. As of 2001, 55 mph is commonly used in 27 states as the regulatory speed limit which is applied on local roads, while 23 states regulate statutory speed limits other than 55 mph on local roads (USDOT, 2001). Table 2.6 describes those states which do not use 55 mph as statutory speed limit on local roads as of 2001.

Table 2.6 States with Statutory Speed Limits other than 55 mph on Local Roads as of 2001

Speed Limit	States
35 mph	Alabama, Georgia and Virginia
40 mph	Massachusetts, South Carolina
45 mph	Maine
50 mph	Delaware, Iowa (between sunset and sunrise), Maryland, Nebraska, Rhode Island (45mph during the nighttime), Vermont and Washington
60 mph	Arkansas (50 mph for trucks), Texas (55 mph during the nighttime)
65 mph	Alaska, Arizona, Minnesota (during the daytime), Mississippi (55mph for trucks or truck-trailers), Tennessee, Wyoming
70 mph	Montana (65 mph during the nighttime)
75 mph	Nevada, New Mexico

(Source: USDOT, National Highway Traffic Safety Administration, 2001)

In Kansas, the Statutes requires that "*no person shall operate a vehicle at a speed in excess of 55 miles per hour on any county or township highway*" and that "*based on engineering and traffic investigations, a local government may increase or decrease the above speed limits within its jurisdiction, however, the speed limit cannot be less than 20 MPH outside an urban or residence district*" (Kansas Legislature, 2006).

A few states have established specific speed limit for gravel roads. For example, Georgia has 35 mph as the unpaved road speed limit by requiring that "*no person shall drive a vehicle at a speed in excess of 35 miles per hour on an unpaved county road unless designated otherwise by appropriate signs*" (Georgia Legislature, 2007). In South Carolina, it was regulated that "*unpaved roads are limited to the speed of 40 miles per hour*" (South Carolina Legislature, 2007). Alabama and Nebraska also have specific speed limits for gravel roads.

2.4.4 Concerns Regarding Speed Limits on Gravel Roads

In Michigan, the State Police researched and developed criteria for correlating the appropriate speed limit to the number of access points on gravel roads. A law was approved in

2006, which allows local road agencies to establish “prima facie speed limit” on gravel roads based on the number of access points per mile, i.e., 25 mph on a road segment with 60 or more access points within 0.5 mile, 35 mph on a road segment with 45 to 59 access points within 0.5 mile, 45 mph on a road segment with 30 to 44 access points within 0.5 mile (Michigan Legislature Council, 2006). Another bill was passed on June 2007 in the Michigan Senate to allow the local government in Oakland County to post gravel or dirt roads, which were previously posted with 25 mph signs, with lower limit signs than the 55 mph “prima facie” speed limit on the basis of the number of residences on the road, regardless of whether it is paved (Michigan Votes, 2007).

An extensive online search found that a number of local jurisdictions do not think the use of speed limits on gravel roads is practical due to the easily changeable surface conditions of gravel roads. For example, Franklin Regional Council of Governments (FRCG) in Massachusetts indicates that an ideal speed limit on gravel roads should be both acceptable to prudent drivers and enforceable by police departments and that gravel roadways are not typically speed zoned due to the fact that it is impossible to establish a consistent road surface and conditions on gravel roads which tend to change over a relatively short period of time (FRCG, 2001). Minnesota Department of Transportation (Mn/DOT) states that “*gravel roads are designed with minimal design criteria, are subject to fluctuating surface conditions, have low enforcement priority, and serve low ADT's usually comprised of local repeat traffic*”, therefore Mn/DOT has generally not set speed limits on gravel roads (Mn/DOT, 2007). Jackson County of Oregon indicates that no speed zone is used on gravel roads because Oregon Department of Transportation (ODOT) feels that conditions on gravel roads vary too much for a specific speed limit to be appropriate (Jackson Co., Oregon, 2007). The Road Commission in Livingston County, Michigan, also indicates that they only consider posting a speed limit on a gravel road if it meets the criteria specified for prima facie speed limits and absolute speed limits are not considered due to the continuously changing conditions of gravel roadways (Livingston Co., Michigan, 2007).

In Australia, the Department of Infrastructure, Energy and Resources (DIER) indicated that speed limit signs are not installed on unsealed roads (dirt or gravel) as it may imply that there is a safe speed at which motorists should travel on such roads (DIER, Australia, 2004). Whereas, motorists should be aware that the actual safe speed of travel on unsealed roads may vary tremendously within a short space of both time and distance due to weather or road conditions. Based on the thinking of DIER, motorists should be responsible for assessing prevailing weather and road conditions and their own abilities in order to determine an appropriate safe driving speed on unsealed roads.

A speed study was conducted in Oakland County, Michigan, in 1990, which was aimed at studying the effectiveness of residential 25 mph speed limits on both local and primary gravel roads (Vogel, 1990). The 85th-percentile speed was 36.75 mph on posted local roads, and 36.21 mph on unposted local roads, which were virtually identical. On primary roads, the 85th percentile speed was 42.72 mph on posted roads and 45.42 mph on unposted roads, which was found to be significantly different with 99% confidence based on the Z-test. In real terms, the difference of 2.7 mph does not mean a noticeable change to the average driver or resident. This study indicated that it was hard to conclude the 25 mph residential speed limit on gravel roads had affected driver behaviors and that this speed limit served no purpose other than as a 'placebo' to the residents of the affected roadways.

Another study indicated that speed limits should not be established on unpaved roads as roadway characteristics such as terrain, surface conditions, geometric alignment, and sight distance may combine as positive guidance to dictate the safe speed of an unpaved road (Neeley, 1995). Posting inappropriate signs might breed disrespect for all signs. It was advised to regulate speeds using measures other than speed limits in those instances where safe speeds can vary with changing roadway conditions and where road characteristics help regulate speed.

2.5 Safety on Gravel Roads

This section reviews some safety related studies with relation to gravel roads, which studied the effects of traffic speed on safety.

A study was conducted to study the relationship between accidents and roadway width on 4,100 miles of two-lane low-volume roads in seven states including Alabama, Michigan, Montana, North Carolina, Utah, Washington and West Virginia (Zegeer et al, 2004). Difference was compared between paved and unpaved roads in three lane width categories which are respectively ≤ 9, 10 ~11, and ≥ 12 ft. It was found that unpaved roads had higher accident rate and injury rate than paved roads and that unpaved roads with ADT higher than 250 vehicles per day had significantly higher accident rates than paved roads. It was also found that accident rate increased as road widths of unpaved roads increased, which was a reverse situation of what was found on paved roads. The situation was explained by saying that drivers might have reduced their speeds on very narrow unpaved roads, thereby decreasing accident rates (Zegeer et al, 2004). Another study found injury crash rate on selected Wyoming unpaved road sections was more than five times higher than the rate for overall roads within the state (Calvert and Wilson, 1999).

A crash study conducted in Nebraska studied the probabilistic linkage of crash, emergency medical services, and hospital data for 1999 and 2000 in Nebraska by using Crash Outcome Data Evaluation System (CODES) 2000 software (Dhungana and Qu, 2005). Based on speed limit, roads were categorized into three groups: < 50, 50, and > 50 mph. It was found that gravel surface was an additional risk factor and contributed to unexpected severity of crashes on 50 mph posted roads. This study suggested that additional training be given to student drivers and level of law enforcement be increased on gravel roads.

An accident analysis was conducted on very low volume roads in ten counties in Minnesota (Wade et al, 2004). A five-year accident data set was used in that study and the conclusions was that, in addition to improper driving, there were many other factors related to accidents on low-volume roads, such as collision with an animal, which was a most important contributing factor towards accidents on highways with ADT less than 400 vehicles per day. Chi-Square analysis was also performed to compare the association between driver error with accident severity, daylight condition, and location of the first harmful event. The same analysis was also performed to compare association between accident severity with daylight condition and location of the first harmful event. Analysis results revealed significant dependence between driver error with accident severity and location of the first harmful event while no significant relationship could be observed for the remaining three comparisons.

There was another related crash study which analyzed 1993-1995 crash data on low-volume rural roads in Kentucky and North Carolina (Stamatiadis et al, 1999). The Quasi-Induced Exposure method was used in this study as the exposure other than conventional vehicle miles traveled. Relative Accident Involvement Ratio (RAIR), which is the ratio of percentage of at-fault drivers/vehicles for a given set of characteristics to percentage of not-at-fault drivers/vehicles for the same set of characteristics, was used to derive relative crash propensities for different groups of drivers and vehicles. A RAIR greater than 1.0 indicated a high likelihood of crash involvement for that group. This study concluded the following findings for low-volume roads: a) low-volume roads present similar crash trends as other types of roads; b) drivers younger than 25 and older than 65 have higher crash propensities than middle-aged drivers; c) female drivers are safer on average than male drivers; d) young drivers (<25) have more single-vehicle crashes while drivers over 65 have more two-vehicle crashes; e) drivers of older vehicles have more two-vehicle crashes than drivers of newer vehicles; f) in single-vehicle crashes, drivers of older vehicles are more likely to have a serious injury than drivers of newer vehicles; and g) large trucks have the highest two-vehicle crash propensity on low-volume roads, followed by sedans, pickup trucks, vans and station wagons (29).

CHAPTER 3 - Data Collection

This chapter describes the data collections conducted to achieve the objectives of this research, which include: a) speed data collection, and b) crash data collection. Speed studies were performed to collect actual speeds of vehicles and roadway characteristics on a sample of gravel roads. Crash data were used for statistical analysis to evaluate the effects of different speed limits on traffic safety of gravel roads. The first section describes the criteria for site selection, field study, speed collection, and summary of measured characteristics and roadway features. The second section describes the crash database, data preparation and variable selection.

3.1 Speed Data Collection

This section presents the details of collecting speed data on a number of sites on gravel roads in Kansas. The subsection 3.1.1 describes the criteria used in selecting appropriate study sites. The subsection 3.1.2 summarizes the field studies and shows some pictures of gravel roads with relevant comments. The procedure and outputs of speed collection are presented in the subsection 3.1.3.

3.1.1 Site Selection

Study sites are better selected on the sections of gravel roads where free flow speeds can be observed without external influences from roadway characteristics during the data collecting process. The guiding philosophy behind speed studies is that measurements should include drivers freely selecting their speeds, unaffected by traffic congestion or any other special characteristics (Roess et al, 2004). As suggested by Roess et al, study locations are usually not selected at the points of roads after which drivers tend or start to decelerate due to various situations like a curve or a narrow bridge. So the general criteria for selecting sites was to avoid any potential effects from environmental or roadway geometric elements. Another consideration is that speed study should be performed in different counties that have different speed limits and surface characteristics on gravel roads. In this study, gravel, stone, and sand surfaced roads have been studied, and earth surfaced roads were not considered. Private driveways and dead end roads which may be gravel surfaced were not considered either. A summary of criteria for site selection used in this study is presented in Table 3.1.

Table 3.1 Criteria for Site Selection on Gravel Roads

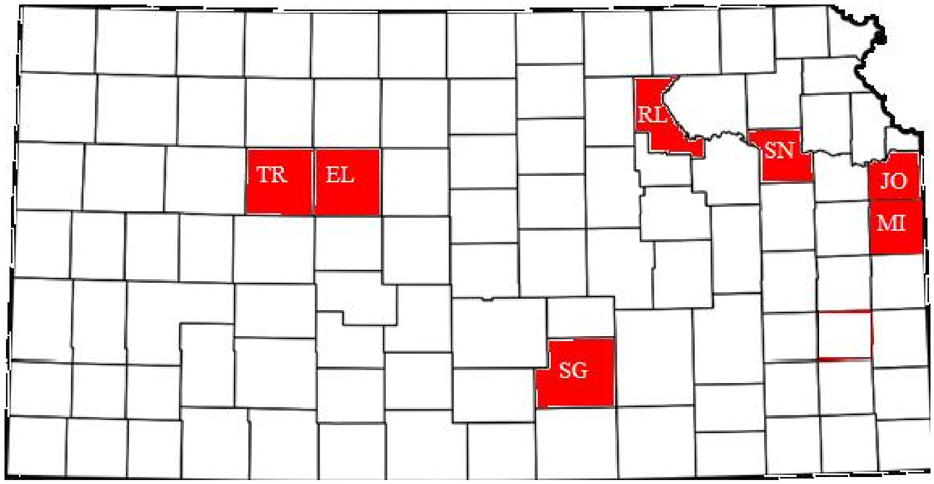
Control Element	Criteria
Sight Distance	Adequate, i.e., no obstruction affects the visibility of motorists from both directions
Terrain	Level
Grade	Approximately 4% to -4%
Surface Condition	Fair to Good
Surface Material	Gravel, crushed stone, sand, or a mixture of forenamed
Distance from Adjacent Horizontal Curve	More than 0.1 mi
Distance from Adjacent Bridge or Access Point	More than 0.2 mi
Distance from Adjacent Signal, STOP sign or Intersection	More than 0.4 mi

Data were collected on forty-one sites in seven counties of Kansas, which are as follows:

- 25 sites in Riley County,
- 5 sites in Johnson County,
- 4 sites in Miami County,
- 2 sites each in Sedgwick, Ellis and Trego Counties, and
- 1 site in Shawnee County.

Figure 3.1 shows the seven counties which have been selected for speed data collection on gravel roads.

Figure 3.1 Seven Counties Selected for Data Collection



3.1.2 Field Studies

Figures 3.2 through 3.11 display some typical gravel roads with various characteristics. Figures 3.2 and 3.3 show two locations on the same gravel road, where it can be seen that the two surfaces had quite different conditions. The road surface in Figure 3.2 was well maintained with adequate amount of crushed rocks, though several rock strips have been formed in the middle and along the edges. In Figure 3.3, a few potholes were formed in the middle of the road and water was collecting in the potholes. It was also observed the second location had obviously less amount of gravel than the first location.

Figure 3.2 Marlatt Ave. Location #1 in Riley County, Kansas

Figure 3.3 Marlatt Ave. Location #2 in Riley County, Kansas

Figure 3.4 displays another comparison of two different locations on one gravel road. Apparently these two locations are maintained with different materials. The location shown in Figure 3.4 (a) has a darker surface than the location in Figure 3.4 (b).

Figure 3.4 Two Locations on W 231st St. in Miami County, Kansas

(a) (b)

Figure 3.5 shows a gravel road in Johnson County, which has a 35 mph speed limit sign on the right side. It was found that all the gravel roads in Johnson County have been posted with 35 mph speed signs. The gravel roads in Johnson County were observed as well-maintained with adequate amount of crushed rocks on the road surfaces.

Figure 3.5 Moonlight Rd. in Olathe, Johnson County, Kansas

Different speed limits are sometimes used according to the locations and situations. Figure 3.6 shows a gravel road posted with 40 mph sign in the City of Lawrence. Figure 3.7 shows a 30 mph gravel road in a relatively urban residential area in the City of Wichita.

Figure 3.6 Queens Rd. in the City of Lawrence, Kansas

Figure 3.7 N Clara St. in the City of Wichita, Kansas

Figure 3.8 shows an uncontrolled intersection between two gravel roads which is clear of all types of signs. This type of intersection was observed to be widely used on gravel road intersections in Ellis County. In comparison, gravel road intersections are usually two-way stop-controlled in most of the counties in the eastern part of the state, such as Riley and Miami Counties.

Figure 3.8 A Gravel Road Intersection in Ellis County, Kansas

Figure 3.9 shows a typical sand road in Trego County, in comparison to the gravel or stone roads in the counties of the eastern part of Kansas, such as the gravel roads having been shown in Figures 3.2 through 3.7.

Figure 3.9 Golf Course Rd. in Trego County, Kansas

Figure 3.10 shows a steep uphill vertical curve on a sand-surfaced road, where a warning sign cautioning the steep slope and limited sight distance could be helpful for drivers to safely pass through.

Figure 3.10 A Steep Vertical Curve on Golf Course Rd. in Trego County

The huge amount of dust that is produced by moving traffic could cause potential danger to the following drivers by reducing their visibilities, as shown in Figure 3.11. In general, the higher the speed, the larger the amount of dust that is produced on gravel roads.

Figure 3.11 Huge Amount of Dust on Gravel Roads

The figures presented earlier imply that the features of gravel roads like surface conditions significantly vary at different locations. Two different gravel roads or even two different sections on the same road may have unique surface features and characteristics. This does not usually happen on paved roads which can maintain the same conditions for very long period of time and distance. Ruts, potholes and washboards were frequently observed on gravel roads during the field studies, especially on those roads that are not routinely maintained. As observed during the field studies, damaged road surfaces require drivers to be more prudent and travel at lower speeds than on well-maintained roads.

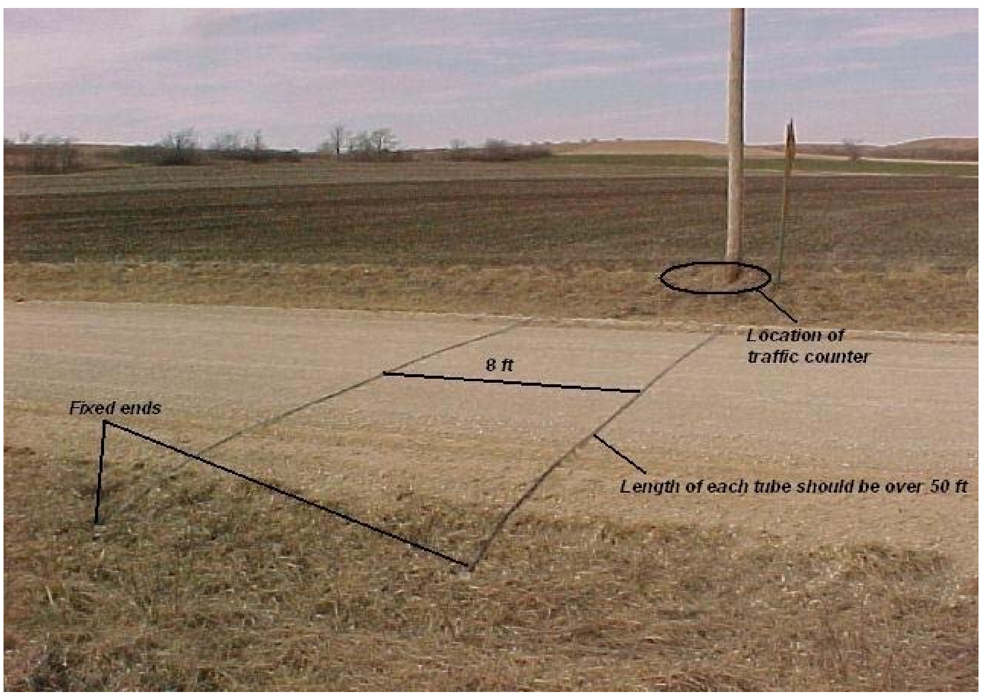
Accordingly, a set of basic road characteristics were recorded during the field studies. The following features were recorded: road width, speed limit, surface classification as introduced in the following sections, and weather condition. Some common features of paved roads (such as functional class, number of lanes, shoulder and roadside development) do not apply to the studies on gravel roads.

3.1.3 Speed Data Collection

Radar guns were not used in this study due to too low traffic volumes on gravel roads. Moreover, using radar guns for collection of speed data is very likely to affect traffic on gravel roads since motorists could easily see observers on roadside and change their speeds. In this study, two sets of JAMAR TRAX I Plus automatic traffic counters were used for data collections.

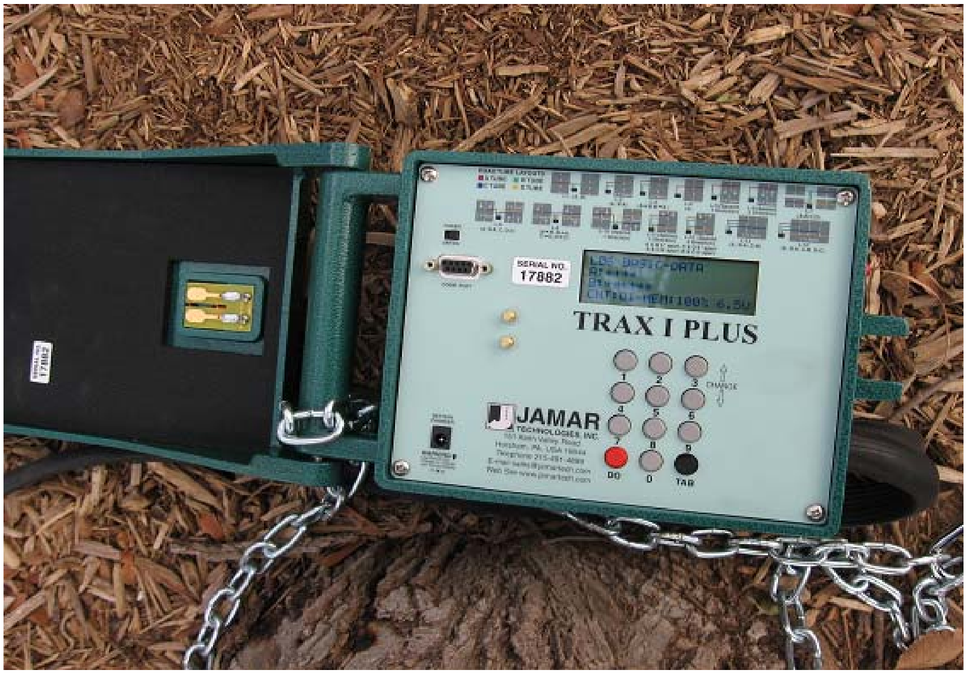
Each set of counters consists of a traffic counter, two pneumatic tubes (sensors) and some accessories. Figure 3.12 shows the standard configuration of one set of traffic counters. The spacing between the two sensors is eight feet. Two ends of the sensors are fixed on the shoulder, and the other two ends are connected to the traffic counter.

Figure 3.12 A Typical Setting up of the Traffic Counter



When a vehicle passes over the sensors, air pulses are sent to the counter that can be directly observed on the screen as stars are added onto the corresponding sensors, as shown in Figure 3.13. At the meantime, two time stamps are recorded in the counter as raw data, which are analyzed with special analysis software (TRAXPro) provided by the manufacturer to produce the output of speed measurements.

Figure 3.13 The Interface of a Traffic Counter



The output consists of a combination of speed values, including mean speed, pace and 85th-percentile speed. Other related traffic information including ADT, vehicle distribution by classification, percent of vehicles exceeding speed limit are also provided. The automatic traffic counters are well designed for data collection on very low-volume gravel roads since they can work in the field for a long duration without needing much attendance. The sensors used in this study were half-round (D) tubes, which can sustain heavier damages from traffic and materials of road surfaces than normal round tubes which are usually used on paved roads. The duration of data collection was usually one week at each site, subjected to change based on weather or traffic conditions.

Two drawbacks of this data collection method were also noticed as follows:

1. It is difficult to identify any abnormal speed observations because of the automatic recording and data processing. For example, some speed observations could be very low such as lower than 15 mph and need to be checked for normality using statistical methods.

2. The data collection process could be accidentally terminated because large vehicles, especially farm equipments, can easily damage or cut the sensors while passing over and hence interrupt the collection of data.

Figure 3.14 shows a school bus passing over the sensors at one of the sites. School buses were frequently observed traveling on gravel roads to transport students who reside in rural areas.

Figure 3.14 A School Bus Passing over the Pneumatic Sensors

Spot speed studies usually identify vehicles having a minimum headway as free-flowing vehicles. A previous study defined a free-flowing vehicle as having a 5-second headway and a 3-second tailway (Fitzpatrick et al, 2003). Based on that criterion, in this study, the field observations showed that more than 99% of vehicles on the study sites had headway over 10 seconds due to low ADT values. Therefore, all the collected speed data can be considered as free-flowing speeds that were not affected by proceeding vehicles.

Based on the amount of gravel on the surface, gravel roads are classified into three groups, including G1, G2 and S, as shown in Figure 3.15. A surface with a smaller amount of gravel is coded as "G1" as shown in Figure 3.15 (a). A gravel surface having a large or moderate amount of gravels or crushed rocks is coded as "G2" as shown in Figure 3.15 (b). The code of "S" denotes those gravel roads with sand surfaces as shown in Figure 3.15 (c). This classification is based on subjective observations at the time of data collection and is prone to change from time to time with grading work carried out by maintaining personnel. The three above codes are used as dummy variables in the statistical analysis of speed data.

Figure 3.15 Description of Gravel Surface Classifications

(a) (b) (c)

The collected speed data and related characteristics of gravel roads that have been studied are presented in Chapter 5.

3.2 Crash Data Collection

In this study, Kansas Accident Recording System (KARS) database was used to obtain crash data on gravel roads over the period 1996-2005. Statistical analyses were then carried out to identify general characteristics and to see whether speed limit has effects on the occurrence and severity of crashes on gravel roads.

3.2.1 KARS Database

KARS is a comprehensive crash database comprising of all police reported crash data in Kansas. The KARS database include detailed information pertaining to each crash related to the driver, occupant, environment, road and vehicle, crash severity, surface type, date and time, contributing circumstances based on police judgment among many others. In the Microsoft Access database, every crash record has a unique accident key which is used as an identifier to recognize each individual crash. With the accident key, relationships can be created between different tables in the database so that queries are developed over two or more tables to obtain useful information.

In the "ACCIDENTS" table of the KARS database, there is a field ON_ROAD_SURFACE_TYPE (ORST) which indicates the surface type of the road on which the corresponding crash occurred. Five double-digit numbers (01 to 05) are coded in this field, which respectively stands for: 01 – concrete; 02 – blacktop; 03 – gravel; 04 – dirt; and 05 – brick. To produce a combined table with only gravel surface left in the final table, the criteria in the query is to set the ORST field as "03". Crashes were classified into five categories based on severity: fatal, disabled, non-incapacitating, possible, and Property Damage Only (PDO) crashes, which was defined based on the highest reported personal injury severity sustained by an involved occupant. In this study, a total of six tables were combined to develop a new table having the variables of interest. For more information about KARS, one is referred to the "*Motor Vehicle Accident Report Coding Manual*" published by KDOT (KDOT, 2005).

3.2.2 Data Preparation

The crash data used in the study were prepared by making queries in the original database to produce crosstab relation tables with those factors of interest. Abnormal records which have missing fields or strange values were discarded. Eventually a total 41,613 gravel road crash records were considered in the study. The crash data were used to develop contingency tables with two factors of interest respectively in the row and column, such as speed limit and crash severity. The contents of the contingency tables were the obtained crash frequencies corresponding to each category of the factors in row and column.

An extensive dataset was prepared for carrying out logistic regression aimed at identifying the effects a set of characteristics on crash severity. The original database was retreated by incorporating as many variables as possible into the new dataset. To study the impact of speed limit on crash severity, the total dataset was split into five sub-datasets based on crash severity. The five datasets include: 1) crashes with all five severities, 2) crashes with all severities but fatal, 3) crashes with all severities except fatal and non-incapacitating, 4) crashes with possible and PDO, and 5) crashes with only PDO. These datasets were used to estimate the impacts of a set of independent variables on different crash severities by using the logistic regression method which is introduced in Chapter 4.

CHAPTER 4 - Methodologies

This chapter introduces the methodologies which have been used in this study. Four statistical methods are used, two of which are for speed data analyzing, and the other two for crash data. For speed data, the two statistical methods used are two-sample t-test and linear regression. For crash data, chi-square test and logistic regression methods are applied. All the statistical analyses were performed using the SAS software. The methodology used for conducting questionnaire surveys is also described in this chapter.

4.1 Methodologies for Speed Data analyses

This section introduces the basic information on two sample t-test and linear regression used for speed data analyses.

4.1.1 Two-Sample t-test

Two-sample t-test is a hypothesis test for answering questions about the mean where the data are collected from two random samples of independent observations, each from an underlying normal distribution (Quantitative Methods in Social Sciences, Columbia University, 2007). For given two samples, two-sample *t*-test compares the mean of the first sample minus the mean of the second sample to a given number (SAS Onlinedoc, 2007). Some underlying assumptions need to be satisfied to apply the two sample t-test. Otherwise different methods or calculations need to be carried out. These assumptions are as follows (SAS Onlinedoc, 2007):

- The observations from two groups are normally distributed
- The variances of two groups are equal
- The observations in each group are independent of those in the other one

The normally used Chi-Square Goodness-of-Fit test method for checking normal distribution of spot speed data is not used in this study due to the too large sample sizes, i.e., more than 7,000 in some group. In this study, the normal distribution of data is checked with the Kolmogorov–Smirnov test (K-S test) method, which is usually applied to determine whether an underlying probability distribution differs from a hypothesized normal distribution. Since the computation of K-S statistic is very complicated, the equations used in K-S test are not introduced here. For detailed information regarding K-S test, refer to SAS Onlinedoc (2007).

The null hypothesis for t-test is that the means of the two groups are equal, and the alternative hypothesis is specified by that the means of the two data groups are not equal. An alpha value is usually specified to determine the significant level on which a null hypothesis is rejected. In t-test for independent groups, the t-statistic is computed by applying the following formulas as described in Equations 1 through 5 (SAS Language, 1990).

Equal Sample Sizes

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(s_1)^2 + (s_2)^2}{n}}} \quad (1)$$

Where,

t = estimated t-value,

$\bar{X}_1$ = mean of group 1,

$\bar{X}_2$ = mean of group 2,

s_1 = standard deviation of group 1,

s_2 = standard deviation of 2,

n = number of observations in each group.

The degree of freedom for this type of data is 2n – 2.

Unequal Sample Sizes with Equal Variance

$$t = \frac{\bar{X}_1 - \bar{X}_2}{s_{\bar{X}_1 - \bar{X}_2}} \quad (2)$$

Where,

t = estimated t-value,

$\bar{X}_1$ = mean of group 1,

$\bar{X}_2$ = mean of group 2, and

$$s_{\bar{X}_1 - \bar{X}_2} = \sqrt{\frac{(n_1 - 1){s_1}^2 + (n_2 - 1){s_2}^2}{n_1 + n_2 - 2} \left(\frac{1}{n_1} + \frac{1}{n_2}\right)} \quad (3)$$

Where,

s = grand stand deviation,

s_1 = standard deviation of group 1,

s_2 = standard deviation of group 2,

n_1 = number of observations in group 1,

n_2 = number of observations in group 2.

The degree of freedom for this type of data is $n_1 + n_2 - 2$.

Unequal Sample Sizes with Unequal Variance

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{4}$$

Where,

t = estimated t-value,

$\bar{X}_1$ = mean of group 1,

$\bar{X}_2$ = mean of group 2,

s_1 = standard deviation of group 1,

s_2 = standard deviation of group 2,

n_1 = number of observations in group 1,

n_2 = number of observations in group 2.

The degree of freedom for this type of data is computed by Eq. 5.

$$df = \frac{(s_1^2/N_1 + s_2^2/N_2)^2}{(s_1^2/N_1)^2/(N_1-1) + (s_2^2/N_2)^2/(N_2-1)} \tag{5}$$

A critical t-value can be obtained from the standard table of t-values based on the significance level and the degree of freedom. The comparison between the calculated t-value and critical t-value leads to a determination on whether or not the null hypothesis can be rejected at the selected level of significance. The TTEST procedure of SAS software was used in this study to calculate the t-values. P-value is the main indicator of t-test on validating the null hypothesis, which can be interpreted as: when p-value > 0.05, the null hypothesis is accepted and the alternative hypothesis is rejected with 95% confidence (i.e. the means of the two groups are not significantly different); when p-value < 0.05, the null hypothesis is rejected and its alternative hypothesis is accepted (i.e. the two means are significantly different).

4.1.2 Multiple Linear Regression

Regression analysis is a statistical methodology that utilizes the relation between two or more quantitative variables so that one variable can be predicted from the other, or others (Neter et al, 1996). Multiple Linear Regression (MLR) is an extension of simple linear regression and can be used to account for the effects of several independent variables simultaneously. The general multiple linear regression model is defined in terms of X variables as in Eq. 6 (Weisherb, 2005):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p \quad (6)$$

Where,

Y = dependent variable,

β_0 = equation constant,

$\beta_1, \ldots, \beta_p$ = partial regression coefficients,

$X_1, \ldots, X_p$ = independent variables.

Regression problems start with a collection of potential predictors, which may be continuous, discrete but ordered, or categorical measurements. A categorical predictor with two or more levels is called a *factor,* which consists of the same number of dummy variables as the levels. Dummy variables are included in MLR with a value of 0 or 1, indicating whether this category is present for a particular observation. A few dummy variables are considered in the MLR modeling process in this study. When the distribution of observations is verified to be normal, the method of Ordinary Least Squares (OLS) is suggested to obtain estimates of parameters for independent variables in a model. The logic of OLS method is that parameter estimates are chosen to minimize a quantity called the residual sum of squares (RSS). The most important results, estimated parameter $\hat{\beta}$s can be calculated with the following Eq. 7 (Weisherb, 2005):

$$\hat{\boldsymbol{\beta}} = (X'X)^{-1}X'Y \quad (7)$$

Where,

$\hat{\boldsymbol{\beta}}$ is the parameter vector excluding the intercept β_0,

$X'X$ and $X'Y$ are matrices of uncorrected sums of squares and cross-products, which are as described in Eq. 8:

$$X'X = \begin{pmatrix} n & \sum x_i \\ \sum x_i & \sum x_i^2 \end{pmatrix} \text{ and } X'Y = \begin{pmatrix} \sum y_i \\ \sum y_i^2 \end{pmatrix} \quad (8)$$

Thus the intercept is defined by Equation 9 as follows:

$$\hat{\beta}_0 = \bar{y} - \hat{\boldsymbol{\beta}}\bar{\boldsymbol{x}} \quad (9)$$

Where,

$\bar{y}$ is the mean of observations,

$\bar{x}$ is the vector of sample means for all the terms except for the intercept.

The analysis of variance is a technique to compare mean functions that include different nested sets of terms. This technique can be used to test the importance of a whole set of terms or just one term of the set. For an overall term test, null hypothesis is built as $\beta_i = 0$ (for i = 1, 2, 3, ⋯, p) with alternative hypothesis specified as that at least one parameter of $\beta_i \neq 0$. P-value corresponding to F-test is used to determine whether to accept the null hypothesis or to reject it by comparing with a critical significance level (0.10 was used in this study).

The R-square (R^2) value, which is the coefficient of determination in linear regression, gives the proportion of variability in Y explained by regression on a set of explanatory variables. It can also be interpreted as the square of correlation between observed values of Y versus fitted values of $\hat{Y}$. R^2 is defined in Eq. 10 (Weisherb, 2005):

$$R^2 = \frac{SS_{reg}}{SYY} \qquad (10)$$

Where,

SS_{reg}

SS_{reg} is the residual sum of squares due to regression,

SYY is the sum of squares for mean function with only intercept considered.

The value of R^2 is in a range of 0 to 1, with 1 indicating that a fitted model perfectly explains the response and 0 indicating that a fitted model cannot explain the response. For further details regarding linear regression model, one is referred to *Applied Linear Regression* (Weisherb, 2005).

The data used in developing linear regression models is presented in Chapter 5. The factors used in MLR are the 85th-percentile speed, mean speed, ADT, width of roadway, surface classification, speed limit, and percent of large vehicles. The measured 85th-percentile speed and mean speed were treated as response variables and the others were predictor variables. The assumption for the regressions is that traffic and roadway features have important effects on traffic speeds, which are represented by the 85th-percentile speed and mean speed. These variables include both continuous and categorical terms. Surface classification and speed limit are categorical variables as shown in Table 4.1, which describes the variables used in the MLR of this study. G1, G2, and SL_{55} are dummy variables. When both G1 and G2 have values of "0", the corresponding road represents a sand-surfaced road. If SL_{55} takes a "0" value, the road is a gravel road posted with 35 mph speed limit since there are only two categories for speed limit.

Table 4.1 Descriptions of Variables Used in Linear Regression Modeling

Variables	Description	Value
FFS_{85th}	85th-percentile speed measured on the site	Continuous in mph
FFS_{mean}	Mean speed measured on the site	Continuous in mph
ADT	Quotient of average daily traffic (ADT) on each study site divided by 100	Continuous in veh/day, in hundreds
RW	Width of roadway under study	Continuous in ft
G1	A lower class of gravel surface (see Figure 3.15)	= 1 if classified as G1 = 0 if no
G2	A higher class of gravel surface (see Figure 3.15)	= 1 if classified as G2 = 0 if no
SL_{55}	55 mph speed limit is applied for the site under study	=1 if yes =0 if no
PLV	Percentage of large vehicles in total traffic	Continuous decimal value

To identify the "best" model, stepwise selection procedure was used to select the most important predictor variables in the MLR. Stepwise selection method checks the mean function to see if any current term is not significant before adding another term, and if so, it drops the most insignificant term. This selection method has been used in many previous linear regression studies (Robert et al, 1998; Liu and Sokolow, 2007; Nie and Hassan, 2007). A 90% confidence level was used in the stepwise method to select those significant variables. The modeling was carried out with the REG procedure of SAS software (SAS Institute, 2007).

4.2 Statistical Methodologies for Crash Data

This section introduces the statistical methods used in analyzing the crash data related to gravel roads in Kansas.

4.2.1 Chi-Square Test

To determine whether or not two variables are independently related, i.e., the two variables have no relationship, chi-square test can be applied. As a straightforward method, chi-square test is used to test the null hypothesis of the existence of independence between two categorical variables which are in two-way or contingency tables. A restriction for this method is that the number of observations in any cells of the observation table should not be less than five. When one of the two variables has large categories, it can be decent for chi-square test when some expected frequencies are less than about 5. Otherwise, fisher's exact test needs to be carried out to analyze the data with small sample sizes (Agresti, 2007). Another surrogate measure is to combine some categories with too few observations to obtain large enough sample, but the combined categories should make actual sense so that the analysis results are interpretable.

In two-way contingency tables with joint probabilities $\{\pi_{ij}\}$ for two response variables, the null hypothesis of statistical independence is:

H_0: $\pi_{ij} = \pi_{i+} \pi_{+j}$ for all i and j

Where,

π_{ij} = the joint probability of the cell between *i*th row and *j*th column

π_{i+} = the marginal probability of the *i*th row

π_{+j} = the marginal probability of the *j*th column

i = the number of rows of the contingency table

j = the number of columns of the contingency table

The null hypothesis means that the joint probabilities can determine each probability π_{ij} in the table (i.e., the two variables are independent). Accordingly, the alternative hypothesis is that the two variables are not independent. Eq. 11 is used to estimate the expected frequencies based on observed data (Agresti, 2007):

$$\hat{\mu}_{ij} = \frac{n_{i+} n_{+j}}{n} \tag{11}$$

Where,

$\hat{\mu}_{ij}$ is the expected value of n_{ij} for the cell between the i^{th} row and the j^{th} column,

n_{i+} is the marginal total of the i^{th} row,

n_{+j} is the marginal total of the j^{th} column, and

n is the grand total of the table.

Here $\{\hat{\mu}_{ij}\}$ are called estimated expected frequencies. They have the same row and column totals as the observed counts, while display the pattern of independence.

For testing independence in $i \times j$ contingency tables, the Pearson and Likelihood-Ratio statistics are computed by Eq. 12:

$$X^2 = \sum \frac{(n_{ij} - \hat{\mu}_{ij})^2}{\hat{\mu}_{ij}}, \quad G^2 = 2 \sum n_{ij} \log \left(\frac{n_{ij}}{\hat{\mu}_{ij}}\right) \tag{12}$$

Where,

X^2 is Pearson chi-squared statistic,

G^2 is Likelihood-Ratio chi-squared statistic.

Both the two statistics have approximately chi-squared distribution for large sample sizes of n. Moreover, both $X^2$and G^2 statistics have degrees of freedom of $(I-1)(J-1)$. Though Pearson and likelihood-ratio statistics provide separate test statistics, they share many properties and usually provide the same conclusions. P-value is used to determine whether to reject a null hypothesis or to accept it, and it is the chi-squared right-tail probability above the observed X^2 value (Agresti, 2007). In this study, 0.05 was selected as the critical significance level. Therefore, a p-value of less than 0.05 is strong enough to reject the null hypothesis by concluding that the two variables being tested are not independent.

When both row and column variables lie on ordinal scales, the Mantel-Haenszel chi-square statistic tests the null hypothesis that there is a linear association between row variable and column variable. The statistic is computed as follows (Agresti, 2007):

$$M^2 = (n-1)r^2 \tag{13}$$

Where,

M^2 is the Mantel-Haenszel chi-square,

n is the sample size,

r^2 is the Pearson correlation between row and column variable, which can be computed with Eq. 14:

$$r = \frac{\sum_{i,j}(u_i - \bar{u})(v_j - \bar{v})p_{ij}}{\sqrt{[\sum_i (u_i - \bar{u})^2 p_{i+}][\sum_j (v_j - \bar{v})^2 p_{+j}]}} \tag{14}$$

Where,

$u_1 \leq u_2 \leq \cdots \leq u_I$ denote scores for the rows,

$v_1 \leq v_2 \leq \cdots \leq v_J$ denote scores for the columns,

$\bar{u}$ denotes the sample mean of the row scores,

$\bar{v}$ denotes the sample mean of the column scores.

The correlation *r* falls between -1 and +1. The larger the correlation is in absolute value, the farther the data fall from independence in the linear dimension. For large n, M^2 has approximately a chi-squared distribution with *df* = 1 (Agresti, 2007). Based on the p-value given with the M^2statistic, the presence of linear relationship between the two variables can be verified.

4.2.2 Odds Ratio

Odds ratio is defined as the ratio of the odds of an event occurring in one group to the odds of it occurring in another group, or to a sample-based estimate of that ratio. Assuming the probability of success to be π, the odds of success are defined with Equation 15:

$$odds = \pi / (1 - \pi) \tag{15}$$

In 2 × 2 contingency tables, the odds ratio (symbolized as θ) is the ratio of the odds in row 1 and the odds in row 2 as follows (Alan Agresti, 2007):

$$\theta = \frac{odds_1}{odds_2} = \frac{\pi_1/(1-\pi_1)}{\pi_2/(1-\pi_2)} \tag{16}$$

The odds ratio can equal any nonnegative number. It equals 1 when the two variables in row and column are independent. When $\theta > 1$, the odds of success are higher in row 1 than in row 2, and adversely, when $\theta < 1$, a success is less likely in row 1 than in row 2.

4.2.3 Logistic Regression

For a binary response variable y, let it have value “1” for “success” and value “0” for “failure”. If the probability for observing a “success” of the response variable y is denoted by $P(Y = 1|X) = \pi(x)$ for a given set of k covariates (i.e. $X = x_1, x_2, \cdots, x_k$), it is the parameter for the binomial distribution and has a logit form as shown in Eq. 17 (Agresti, 2007):

$$\pi(X) = \frac{e^{\alpha+\sum_{i=1}^{k}\beta_i X_i}}{1 + e^{\alpha+\sum_{i=1}^{k}\beta_i X_i}} \tag{17}$$

And the multiple logistic regression model can be written in the following form:

$$logit[\pi(x)] = log\left(\frac{\pi(x)}{1-\pi(x)}\right) = \alpha + \sum_{i=1}^{k}\beta_i X_i \tag{18}$$

Where,

α is the intercept,

$\{\beta_i\}$ are regression coefficients for covariates X.

The parameter β_i refers to the effect of x_i on the log odds that Y = 1, controlling the other xs. For example, exp (β_i) is the multiplicative effect on the odds of a 1-unit increase in x_i, at fixed levels of the other xs (Agresti, 2007).

The regression coefficients are estimated using maximum likelihood method, which maximizes the log-likelihood function as follows to obtain the best fitted model:

$$logL = \sum_{i=1}^{n} y_i \left(\frac{\pi(X_i)}{1-\pi(X_i)}\right) + \sum_{i=1}^{n} [1 - \pi(X_i)] \tag{19}$$

Where,

L is the likelihood of observing the outcome for all the observations,

y_i is outcome of the i^{th} observation and n is the total number of observations.

The coefficient of determination, R^2, is proposed by Cox and Snell (1989) to assess the effectiveness of the fitted multiple logistic model, which is estimated using the following equation (SAS Onlinedoc, 2007):

$$R^2 = 1 - \left\{\frac{L(0)}{L(\hat{\theta})}\right\}^{\frac{2}{n}} \tag{20}$$

Where,

$L(0)$ is the likelihood of the intercept-only model,

$L(\hat{\theta})$ is the likelihood of the specified model,

n is the sample size.

The quantity R^2 achieves a maximum of less than one for discrete models, where the maximum is given by

$$R^2_{max} = 1 - \{L(0)\}^{\frac{2}{n}} \tag{21}$$

To solve this problem, Nagelkerke (1991) proposed the following adjusted coefficient, which can achieve a maximum value of one:

$$\tilde{R}^2 = \frac{R^2}{R^2_{max}} \tag{22}$$

In SAS output, R^2 is labeled as "R-Square" and $\tilde{R}^2$ is labeled as "Max-rescaled R-Square. To fit data with the best model, stepwise selection method is used to select those most important terms in the final model. The theory for stepwise selection is very similar to that used in linear regression as described in section 4.1.2.

Goodness-of-fit test of logistic models uses three criteria to compare different models for the same data (SAS Onlinedoc, 2007):

- -2 Log Likelihood Criterion (2LLC)
- Akaike Information Criterion (AIC)
- Schwarz Criterion (SC)

In the first criterion, the 2LLC is computed using the following formula:

$$-2LogL = -2\sum_{j} w_j f_j \{r_j \log(\hat{\pi}_j) + (n_j - r_j)\log(1-\hat{\pi}_j)\} \tag{23}$$

Where,

w_j and f_j are the weight and frequency values of the jth observation,

r_j is the number of events,

n_j is the number of observations,

$\hat{\pi}_j$ is the estimated event probability.

Under the null hypothesis that all the explanatory effects in the model are zero, the 2LLC has a chi-squared distribution

The AIC statistic is computed as follows:

$$AIC = -2\,Log\,L + 2p \tag{24}$$

The SC statistic is computed by:

$$SC = -2Log\,L + plog\left(\sum_{j} f_j\right) \tag{25}$$

In Eq. 24 and 25, p is the number of parameters in the model. The lower the three statistics, the more desirably the model fits the data.

In addition, the Hosmer-Lemeshow test (HL-test) is also able to test the goodness-of-fit for binary response models. The HL-test statistic is obtained by calculating the Pearson chi-square statistic from the 2×g table of observed and expected frequencies, where g is the number of groups. The statistic is written as Eq.26:

$$X_{HL}^2 = \sum_{i=1}^{g} \frac{(O_i - N_i\bar{\pi}_i)^2}{N_i\bar{\pi}_i(1-\bar{\pi}_i)} \tag{26}$$

Where,

N_i is the total frequency of subjects in the *i*th group,

O_i is the total frequency of event outcomes in the *i*th group,

$\overline{\pi}_i$ is the average estimated probability of an event outcome for the *i*th group.

The Hosmer-Lemeshow statistic is then compared to a chi-square distribution with (g – n) degrees of freedom, where the value of n has a default value of 2 in SAS. Large values of X_{HL}^2 (and small p-values) indicate a lack of fit of the model.

4.3 Methodologies for Survey

Surveys were conducted in Kansas to collect public and professional opinions regarding speed limit related issues on gravel roads. Two sets of questionnaires have been prepared. The first survey was conducted among county transportation professionals, such as county engineers and directors of public works, and the second one was a public survey among Kansas rural residents who are supposed to be more concerned about this issue.

In the survey for transportation professionals, respondents were requested to provide basic information related to gravel roads in their counties, such as funding, maintenance frequency, materials and location of resources, etc. The most important question was to see how they would like to set speed limits on gravel roads, i.e., whether they prefer speed zones or blanket speed limits. The respondents were also requested to comment on the current criteria used on setting speed limits on gravel roads.

The public survey collected general information about the respondents, such as their gender, age, driving experiences and overall viewpoints on gravel roads. The respondents were also requested to rank a group of factors which are likely to be important in selecting operating speeds on gravel roads. The respondents were also asked about their opinion on setting speed limits on gravel roads and what they think about the 55 mph statutory speed limit. Both surveys provide free spaces for respondents to make comments regarding the survey and relevant issues.

The samples for these two questionnaires are presented in Appendices A and B. The survey of professionals were conducted in 105 counties, and the gravel road user survey was conducted in seven counties in Kansas, including Johnson, Miami, Leavenworth, Franklin, Smith, Douglas and Riley Counties. Both surveys were conducted by mailing the survey forms to the respondents. Some responses were received by faxes and emails from the transportation professionals. After collecting the response letters, a total of 79 responses were received for the survey of professionals, and 350 responses were collected for the road user survey. The results of analyzing these responses are presented in Chapter 6.

CHAPTER 5 - Results of Data Collection and Analyses

The results of data collection and analysis of speed and crash data are presented in this chapter. Sections 5.1 and 5.2 discuss the speed data on gravel roads and the statistical analyses based on the methodologies described in Chapter 4. The crash data and results of statistical analyses are described in Sections 5.3 and 5.4.

5.1 Results of Speed Data Collections

The summary results of speed data collections are presented in Table 5.1. The values in 4th through 6th columns are characteristics directly observed from the study sites, and the values in the last seven columns are obtained using the JAMAR traffic counters.

As Table 5.1 shows, twelve sites were identified as having surface type “G1”, twenty-six sites were identified as surface type “G2”, and three sites are identified as surface type “S”. The ADT values on these collection sites have been observed to be relatively low varying from 16 to 334 vehicles per day. 78% of the gravel roads have an ADT less than 100 vehicles per day. Road widths range from 16 to 26 ft, and 90% of the roads are wider than 20 ft.

Five gravel roads were studied in Johnson County, where 35 mph speed limit signs are posted. Two 30 mph posted gravel roads in urban areas of Sedgwick County were also studied. Percentages of heavy vehicles in daily traffic on gravel roads vary from 4.7% to 45.8% with a mean of 20.7%. The observed 85th-percentile speeds have a range from 27 mph with an urban gravel road to 67 mph with a sand surfaced gravel road. It was noticed that the percent of vehicles exceeding speed limit (PESL) is very high in Johnson County varying from 36% to 77%. Sand-surfaced roads were also observed to have relatively higher 85th-percentile speeds and larger PESL values than gravel roads.

Table 5.1 Data Summary on Gravel Roads in Kansas

ID	County	Location	Surface Classification	Road Width (ft)	Speed Limit (mph)	ADT (veh/ Day)	Percentage of Heavy Vehicles	**85th-Percentile Speed**	Mean Speed (mph)	Pace (mph)	Percentage in Pace Speed	Percentage Exceeding Speed Limit
1	Riley	Marlatt Ave	G2	24	55*	47	18.6%	**45**	38	36-45	57.6%	0.0%
2	Riley	Riley 424	G2	24	55	72	45.8%	**46**	36	26-35	55.6%	0.0%
3	Riley	Riley 911	G2	26	55	52	37.8%	**58**	49	41-50	48.6%	23.4%
4	Riley	Riley 422	G2	24	55	69	20.9%	**53**	44	41-50	45.2%	6.5%
5	Riley	Riley 428	G2	24	55	95	4.7%	**44**	36	31-40	54.3%	0.5%
6	Riley	Tabor Valley (SB/NB)	G2	24	55	38	19.0%	**53**	43	41-50	45.0%	10.3%
7	Riley	Tabor Valley (EB/WB)	G2	24	55	37	15.8%	**50**	43	39-48	47.4%	5.2%
8	Riley	Fairview Church #1	G1	24	55	55	19.0%	**49**	37	36-45	43.8%	4.1%
9	Riley	Fairview Church #2	G1	24	55	24	18.2%	**49**	39	31-40	47.7%	9.1%
10	Riley	Alembic Rd	G2	24	55	46	15.8%	**53**	44	41-50	40.3%	9.3%
11	Riley	N 60th St	G1	22	55	37	19.4%	**50**	41	34-43	40.7%	2.4%
12	Riley	Walsburg Rd	G2	24	55	67	19.3%	**57**	46	46-55	37.9%	18.8%
13	Riley	LK&W Rd	G2	20	55	20	11.9%	**44**	37	31-40	53.0%	0.0%
14	Riley	N 52nd St	G1	20	55	91	35.2%	**44**	34	31-40	38.2%	0.0%
15	Riley	Rocky Ford Rd	G2	22	55	179	10.7%	**35**	29	21-30	51.2%	0.5%
16	Riley	Kitten Creek Rd	G2	22	55	34	7.1%	**40**	34	31-40	50.0%	0.0%
17	Riley	Silver Creek Rd	G1	16	55	25	16.2%	**48**	40	31-40	52.0%	3.1%
18	Riley	W 59th Ave	G2	22	55	103	22.5%	**43**	35	31-40	47.4%	1.3%
19	Riley	N 48th St	G1	22	55	98	19.2%	**42**	35	31-40	53.1%	0.0%
20	Riley	Union Rd	G2	20	55	46	10.5%	**45**	36	31-40	43.5%	0.0%
21	Riley	Homestead Rd	G1	18	55	46	21.8%	**47**	37	28-37	34.7%	4.0%

Table 5.1 contd…

22	Riley	Crooked Creek	G2	20	55	45	42.0%	**46**	39	37-46	52.0%	0.0%
23	Riley	Sherman Rd	G2	16	55	19	23.4%	**39**	32	31-40	57.4%	0.0%
24	Riley	Madison Creek	G2	22	55	16	10.9%	**43**	35	31-40	49.5%	0.0%
25	Riley	Lasita Rd	G1	25	55	18	43.2%	**55**	44	38-47	48.0%	13.8%
26	Shawnee	SW 49th St	G2	24	55	47	21.0%	**42**	34	32-41	45.5%	0.0%
27	Sedgwick	St Louis St	G1	22	30	59	9.0%	**27**	21	17-28	75.3%	3.3%
28	Sedgwick	Doris Rd	G1	24	30	231	8.3%	**29**	23	21-30	60.5%	9.8%
29	Johnson	W 127th St	G2	18	**35**	49	30.4%	**49**	39	36-45	49.2%	69.4%
30	Johnson	S Gardner Rd	G2	20	**35**	114	13.5%	**40**	33	31-40	52.3%	36.4%
31	Johnson	Moonlight Rd	G2	24	**35**	280	11.4%	**47**	38	36-45	49.7%	70.3%
32	Johnson	143rd St	G2	24	**35**	100	25.4%	**50**	42	36-45	45.3%	77.4%
33	Johnson	S Cedar Niles	G2	22	**35**	73	21.1%	**46**	39	36-45	50.3%	67.1%
34	Miami	231st St	G2	22	55	53	21.4%	**46**	37	31-40	43.8%	2.2%
35	Miami	S Moonlight Rd	G2	22	55	143	16.8%	**47**	39	36-45	46.9%	2.6%
36	Miami	S Cedar Niles	G2	24	55	118	14.7%	**44**	35	31-40	39.8%	1.1%
37	Miami	Columbia Rd	G1	22	55	87	20.0%	**45**	39	36-45	41.9%	1.4%
38	Ellis	Vineyard Rd	G1	22	55	334	15.4%	**58**	48	46-55	41.8%	20.0%
39	Ellis	Buckeye Rd	S	24	55	85	31.1%	**63**	53	51-60	37.1%	40.2%
40	Trego	Golf Course Rd	S	22	55	63	37.1%	**67**	54	49-58	36.1%	46.0%
41	Trego	240th Ave	S	20	55	50	24.8%	**50**	42	39-48	46.4%	4.8%

Note: 1. "G1" denotes gravel surfaces with a fairly thin layer of gravel or crushed rocks, usually less than or equal 1" (see Figure 3.13);

2. "G2" denotes gravel surfaces with a relatively thick layer of gravel or crushed rocks, usually over 1" (see Figure 3.13);

3. "S" denotes sand surface (see Figure 3.13);

4. The 55 mph speed limit is stipulated by the Kansas Statutes but not posted on gravel roads.

5.2 Results of Speed Data Analyses

This section discusses the results of statistical analyses of speed data. Prior to the analysis, the speed data obtained from each county were checked for normal distribution with Kolmogorov-Smirnov test (K-S test). The null hypothesis that the data fit normal distribution can be verified if the p-value in the output is greater than 0.05, otherwise there is no evidence that the data are normally distributed. The K-S test results are shown in Table 5.2, where the d-statistics are output of the K-S tests with corresponding p-values. The p-values for each data set are all greater than 0.05, so the speed data in each county fitted normal distribution and t-test can be applied.

Table 5.2 K-S Test Output and Related Statistics for Speed Data by County

County	Sample Size	Mean (mph)	Standard Deviation (mph)	Maximum	Minimum	d-statistic	p-value
Johnson	2,665	37.5	8.6	68.0	14.6	0.0167	0.071
Miami	1,868	35.8	9.2	67.2	10.0	0.0288	0.068
Riley	7,339	38.2	10.6	72.0	9.4	0.0168	0.065
Ellis	2,514	47.0	11.0	78.0	11.2	0.0353	0.120
Trego	518	46.3	13.8	81.0	12.0	0.029	0.150
Shawnee	127	33.2	9.0	51.8	11.1	0.0618	0.150
Sedgwick	1,422	22.4	5.7	42	6.4	0.018	0.150
Total	16,453						

Basic speed statistics in each county are also presented in Table 5.2. The total number of vehicles (sample size) is 16,453. Riley and Shawnee Counties had the largest and least number of observations, respectively. The observed mean speed was observed to be the highest at 47.0 mph in Ellis County and the lowest at 22.4 mph in Sedgwick County. Trego County had the biggest standard deviation of 13.8 mph, while Sedgwick County had the smallest standard deviation of 5.7 mph.

5.2.1 Two-Sample t-tests for Speed Data

Three stages of t-tests were separately carried out to make comparisons between two groups based on different situations, including county, surface classification and road width.

First Stage

Two-sample t-tests were first conducted considering different counties as follows:

1) Test the difference between the mean speeds of Johnson and Miami Counties, which are adjacent counties and use different speed limit criteria (Johnson County sets 35 mph speed limit signs on all gravel roads while Miami County does not)
2) Test the difference between the mean speeds of Johnson County and a combination of Miami, Shawnee and Riley Counties, which have similar road surface characteristics but different speed limit criteria

The t-test results are presented in Table 5.3. For the t-test between Johnson and Miami Counties, the p-value is very small (less than 0.0001), indicating the mean speeds of these two counties were significantly different with 95% confidence. In other words, the 37.5 mph mean speed of Johnson County is significantly higher than the 35.8 mph mean speed of Miami County. This finding is astonishing since Johnson County has a lower speed limit that is posted on gravel roads while Miami County has the statutory speed limit of 55 mph, which is not posted. It looks like the mean speed in Johnson County should be lower than that of Miami County. However, the results indicate the reverse of the expected situation. This might be interpreted as that the motorists in Johnson County neglect the posted speed limit signs and judged their speeds based on other features like roadway conditions.

The p-value for the second t-test comparing Johnson County to other three counties is 0.4154, which implies that there is no evidence that the mean speed of vehicles in Johnson County is different from that of the other three counties. Since the second test had a larger sample size, it could be more powerful in providing the interpretation, which is that when gravel roads with different speed limits have similar roadway, surface, and geometric conditions, the mean speeds do not change significantly.

Table 5.3 Statistics for the t-test Based on County

Test	County	Size	Mean (mph)	Standard Deviation (mph)	F-test for Equality of Variances		t-test	
					F-value	p-value	t-value	p-value
1	Johnson	2,665	37.5	8.6	1.15	0.0008	6.10	< 0.0001
	Miami	1,868	35.8	9.2				
2	Johnson	2,665	37.5	8.6	1.45	<0.0001	-0.81	0.4154
	Combination	9,334	37.6	10.4				

Second Stage

The t-tests in second stage studied the differences between different surface classifications of gravel roads as follows:

1) Between surface class "G1" and class "G2";
2) Between surface class "S" and the combination of "G1" and "G2" which was symbolized as "G"

The results are shown in Table 5.4. The first test was conducted between surface classes "G1" and "G2" that had respectively mean speeds of 41.1 mph and 37.6 mph. The p-value is less than 0.0001, indicating these two classes had significantly different mean speeds. Based on the data, "G1" class gravel roads had a significant higher mean speed than "G2" class gravel roads. The difference was estimated as equal to 3.8 mph.

The second test compared gravel-surfaced roads to sand surfaced roads. From Table 5.4, the p-value is also less than 0.0001. Therefore, sand-surfaced roads had significantly higher mean speed than gravel-surfaced roads. This difference was estimated as equal to 13.2 mph.

Table 5.4 Statistics for the t-test Based on Surface Classification

Test	Surface Class	Size	Mean (mph)	Standard Deviation (mph)	F-test for Equality of Variances		t-test	
					F-value	p-value	t-value	p-value
1	G1	4,052	41.4	10.9	1.18	<0.0001	18.98	< 0.0001
	G2	9,914	37.6	10.0				
2	G	13,966	38.7	10.4	1.18	0.0058	-26.65	< 0.0001
	S	547	51.9	11.3				

Third Stage

The last t-test was conducted to study the mean speeds on gravel roads with different road widths:

- For each pair of 16′, 18′, 20′, 22′, 24′, 25′ and 26′ wide roads

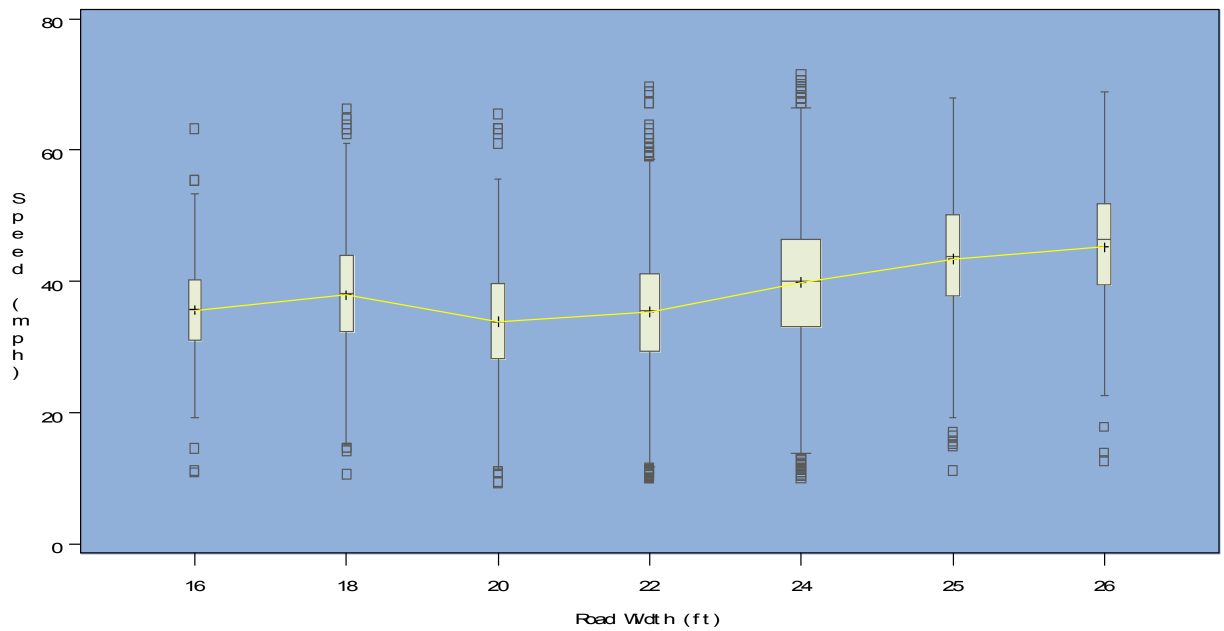
Each test was respectively done for one pair of the seven road widths, such as 16 ft versus 18 ft, 18 ft versus 20 ft and so on. A total of twenty-one tests were carried out and the results are presented in Table 5.5. Only one of the twenty-one p-values is higher than 0.05, which occurred in the test between 16 ft and 22 ft roads. All the other twenty p-values are smaller than 0.05. Therefore, it was concluded that gravel roads with different widths had significantly different mean speeds except for considering the difference between16 and 22 ft roads. It was also noticed that 20 ft gravel roads had the smallest mean speed and 26 ft gravel roads had the highest mean speed than the others.

Figure 5.1 plots the speed statistics based on road width, which shows an increasing trend of mean speeds as road width increases. But this trend applies best only for 20 ft and wider gavel roads. Since this study only considered two sites for each category of 16 ft and 18 ft roads, more collections are needed for a better comparison of mean speed on gravel roads narrower than 20 ft. This estimated trend matches the common sense that drivers tend to drive faster as roads are wider, assuming other conditions are the same.

Table 5.5 Statistics for the t-test Based on Road Width

Test	Road width	Size	Mean (mph)	Standard Deviation (mph)	F-test for Equality of Variances		t-test	
					F-value	p-value	t-value	p-value
1	16′	173	35.7	8.5	1.26	0.066	-2.83	0.0047
	18′	593	37.9	9.5				
2	16′	173	35.7	8.5	1.07	0.57	2.43	0.0151
	20′	1,778	34.0	8.8				
3	16′	173	35.7	8.5	1.15	0.21	0.38	0.7043
	22′	3,906	35.4	9.1				
4	16	173	35.7	8.5	1.44	0.002	-6.46	<0.0001
	24′	5,100	39.9	10.2				
5	16′	173	35.7	8.5	1.55	0.004	-7.82	<0.0001
	25′	192	43.4	10.5				
6	16′	173	35.7	8.5	1.78	<0.0001	-10.74	<0.0001
	26′	257	45.9	11.3				
7	18′	593	37.9	9.5	1.18	0.012	8.96	<0.0001
	20′	1,778	34.0	8.8				
8	18′	593	37.9	9.5	1.09	0.1401	6.30	<0.0001
	22′	3,906	35.4	9.1				
9	18′	593	37.9	9.5	1.14	0.037	-4.77	<0.0001
	24′	5,100	39.9	10.2				
10	18′	593	37.9	9.5	1.23	0.0731	-6.80	<0.0001
	25′	192	43.4	10.5				
11	18′	593	37.9	9.5	1.41	0.0009	-9.90	<0.0001
	26′	257	45.9	11.3				
12	20′	1,778	34.0	8.8	1.08	0.0658	-5.54	<0.0001
	22′	3,906	35.4	9.1				
13	20′	1,778	34.0	8.8	1.35	<0.0001	-23.63	<0.0001
	24′	5,100	39.9	10.2				
14	20′	1,778	34.0	8.8	1.45	0.0003	-12.03	<0.0001
	25′	192	43.4	10.5				
15	20′	1,778	34.0	8.8	1.66	<0.0001	-16.25	<0.0001
	26′	257	45.9	11.3				
16	22′	3,906	35.4	9.1	1.25	<0.0001	-22.24	<0.0001
	24′	5,100	39.9	10.2				
17	22′	3,906	35.4	9.1	1.34	0.0029	-10.41	<0.0001
	25′	192	43.4	10.5				
18	22′	3,906	35.4	9.1	1.54	<0.0001	-14.62	<0.0001
	26′	257	45.9	11.3				
19	24′	5,100	39.9	10.2	1.08	0.4541	-4.73	<0.0001
	25′	192	43.4	10.5				
20	24′	5,100	39.9	10.2	1.24	0.0141	-8.34	<0.0001
	26′	257	45.9	11.3				
21	25′	192	43.4	10.5	1.15	0.3088	-2.35	0.0192
	26′	257	45.9	11.3				

Figure 5.1 Speed Statistics for Different Road Widths



	16	18	20	22	24	25	26
Mean	35.66069	37.93305	33.925	35.36254	39.85362	43.44687	45.20357
Std Dev	8.458432	9.506203	8.651098	9.021913	10.05444	10.53337	10.213

5.2.2 85th-Percentile Speed Model

An 85th-percentile speed model was developed by including six candidate variables described previously in Chapter 4. The data used for modeling are presented in Table 5.1. The two observations on the urban gravel roads in Sedgwick County were not considered in the MLR process due to the number of urban gravel roads in Kansas is too limited to be representative as a group. In addition, characteristics of urban gravel roads appeared to be very different from these of others. The estimated MLR model can be used to identify which of the six variables is important on predicting 85th-percentile speed. Table 5.6 summarizes the estimated parameters and related statistics of the variables that are in the final model.

Based on stepwise selection, four independent variables stayed in the final model as shown in Table 5.6. The two factors, ADT and speed limit, were not included as these two factors were not identified as important predictors based on the p-values. This can be interpreted as ADT and speed limit are not important enough to affect the 85th-percentile speed of traffic on gravel roads. The predicted FFS_{85th} can be determined for a sand surfaced road when both G1 and G2 take value “0”.

Table 5.6 Statistics for the 85th-Percentile Speed Model

Variable	Variable Label	Parameter Estimate	Standard Error	Type II SS	t-value	p-value (Pr > |t|)
Intercept	-	32.733	8.04	378.323	4.07	0.0003
Road Width	RW	1.0114	0.33	209.593	3.03	0.0046
Percentage of Large Vehicles	PLV	16.183	8.28	87.147	1.95	0.0588
Surface Class "G1"	G1	-9.4608	3.22	197.136	-2.94	0.0059
Surface Class "G2"	G2	-12.254	3.06	364.632	-4.00	0.0003
$R^2 = 0.5188$, MSE = 22.801, Alpha = 0.10						

According to the estimated parameters in Table 5.6, the model for predicting 85th-percentile speed on gravel roads could be written as follows:

$$\mathbf{FFS_{85th} = 32.73 + 1.0114(RW) + 16.183(PLV) - 12.254(G2) - 9.4608(G1)} \qquad \textbf{(Eq. 4.1)}$$

Where,

FFS_{85th} = 85th-percentile speed (mph)

RW = Road width (ft)

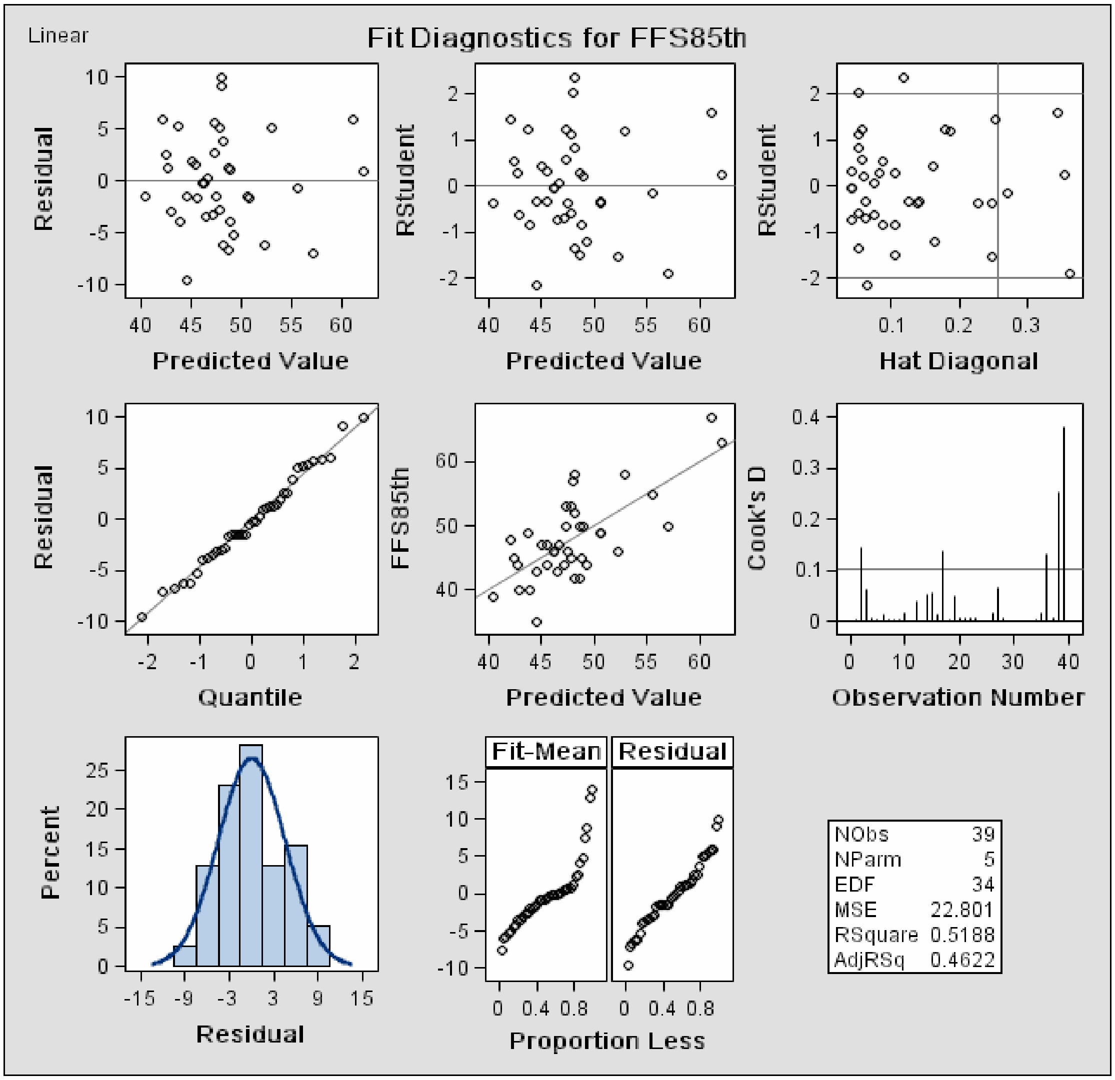
PLV = Percentage of large vehicles in the traffic (decimal)

G2 = Gravel surface classified as "G2" (= 1 if classified as "G2", = 0 otherwise)

G1 = Gravel surface classified as "G1" (= 1 if classified as "G1", = 0 otherwise)

A diagonistical test was performed to study the appropriateness of the fitted linear model in Eq. 4.1. For this purpose, the studentized residuals were plotted against those predicted value and the normal probability plot of residuals was also prepared. These plots were put into Figure 5.2 as a fitting diagostics panel. In Figure 5.2, the plot in the middle of the first row shows studentized residuals against predicted values. Most of residuals fell into the range of (-2, 2) and were averagely distributed around the zero line, and no special patterns could be find in this plot. Both the normal quantile plot of residuals (first plot in the second row) and the residual histogram (first plot in the third row) testify a very good normal distribution of errors. An univariate study was also conducted to test the normality of the errors and gave a d-statistic (from Kolmogorov-Smirnov Test) of 0.085 with a corresponding p-value of 0.15, which also justified the assmption of normal distribution of errors. Hence the good-of-fittness of the estimated model is verified, and the model is feasible for predicting 85th-percentile speed on gravel roads.

Figure 5.2 Fit Diagnostics for the 85th-Percentile Speed Model



The modeling results indicate that both road width and percentage of large vehicles have direct relationship with 85th-percentile speed on gravel roads. While holding other terms constant, one unit increase in road width (i.e. 1 ft) is likely to cause 85th-percentile speed to increase by about 1 mph. And one percent increase of large vehicles probably cause 85th-percentile speed to increase by 0.16 mph. The estimated parameter for G2 implies that, for a given "G2" class gravel road, the 85th-percentile speed on this road is about 12.3 mph lower than that on a sand surfaced road with the same other conditions. In the same way, a "G1" class gravel road possibly has a 9.5 mph lower 85th-percentile speed than a sand surfaced road. 85th-percentile speed on "G1" gravel roads could be 2.8 mph higher than that on "G2" gravel roads.

The R^2 value for the estimated model is 0.5188, indicating that the model in Eq. 4.1 can explain about 51.9% of the variation of the dependent variable, 85th-percentile speed. The fitted linear model is also consistent with the real world situations that wider roads tend to have faster speeds and large vehicles are very likely to be faster than smaller vehicles on gravel roads.

It is inferred from the estimated linear model that both posted speed limits (i.e. 35 mph in this study) and ADT have no significant influences on predicting 85th-percentile speed on rural gravel roads. This finding matches with that from the t-tests discussed in secttion 5.2.1 that speed limits does not affect mean speeds on gravel roads.

5.2.3 Mean Speed Model

A multiple linear model was fitted using the same independent variables as the 85th-percentile speed model to predict the other response variable, mean speed, symbolized as FFS_{mean}. The stepwise selection method identifed the same four independent variables as significantly important predictors, which are summarized in Table 5.7.

Table 5.7 Statistics for Mean Speed Model

Variable	Variable Label	Parameter Estimate	Standard Error	Type II SS	t-value	p-value (Pr > |t|)
Intercept	-	27.79371	6.99514	272.76494	3.97	0.0003
Road Width	RW	0.83655	0.29038	143.39236	2.88	0.0068
Percentage of Large Vehicles	PLV	11.18983	7.20567	41.66634	1.55	0.0162
Surface Class "G1"	G1	-8.92635	2.80085	175.49125	-3.19	0.0031
Surface Class "G2"	G2	-10.57098	2.66741	271.35501	-3.96	0.0004
R^2 = 0.4869, MSE = 17.278, Alpha = 0.10						

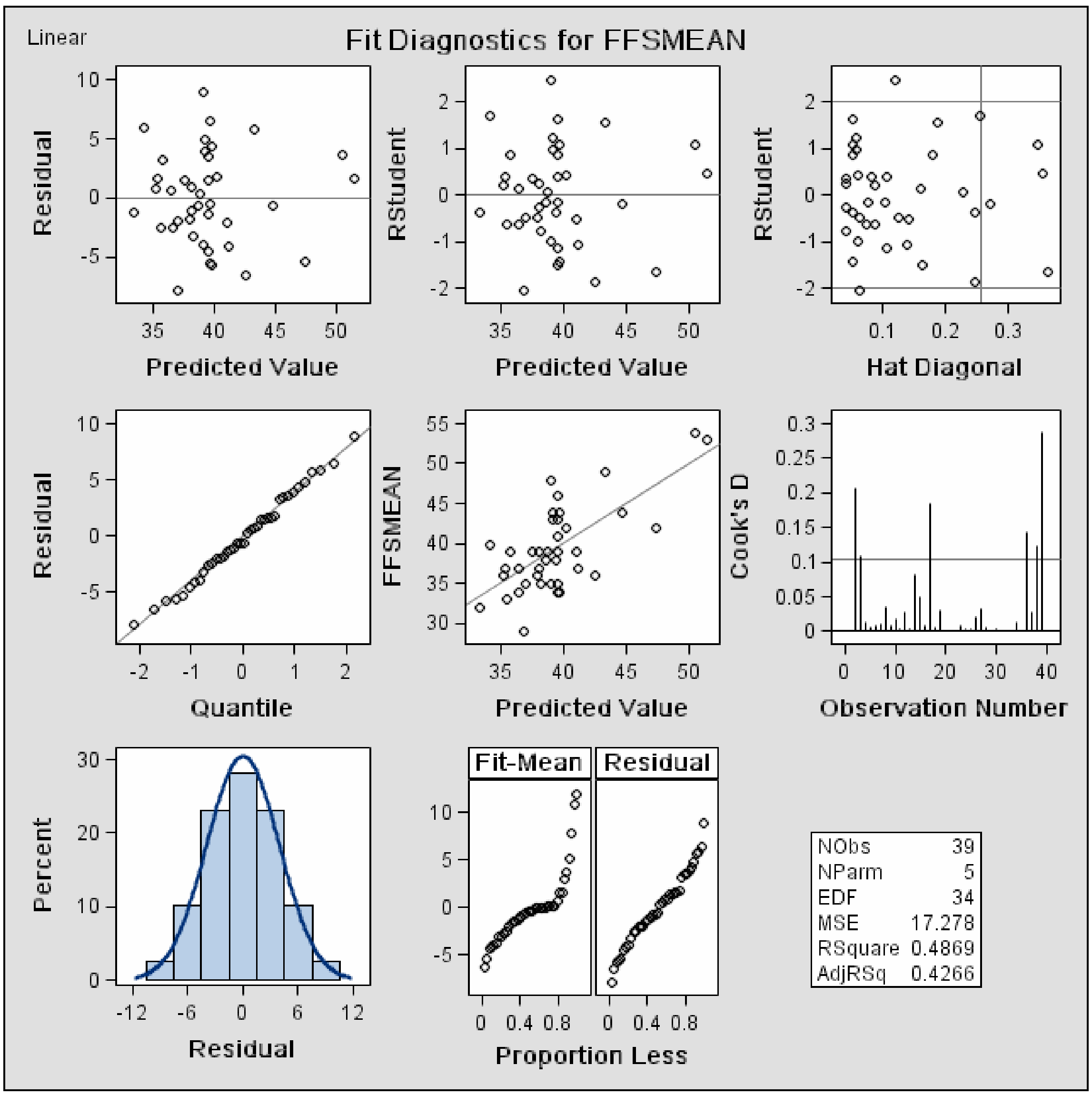
The relationship between the response variable and explanatory variables can be written as follows in Eq. 4.2:

$$\mathbf{FFS_{mean} = 27.794 + 0.8366(RW) + 11.19(PLV) - 10.571(G2) - 8.926(G1)} \qquad \textbf{(Eq. 4.2)}$$

Where, FFS_{mean} = Mean speed (mph) to be predicted, and the other variables are as defined previously in Eq.4.1.

The plots in Figure 5.3 were used to test the goodness-of-fit of the estimated linear model. The studentized residuals are distributed in a range of (-2, 2) with only one value exceeding 2 to a very small extent. No special patterns could be found in the plot of studentized residuals against predicted values. The normal quantile plot of residuals fits a very good linear relationship, and the residual histogram fits an excellent normal distribution as shown in Figure 5.3. The K-S test gave a d-statistic of 0.063 with p-value at 0.15, indicating the residuals are normally distributed. Therefore the estimated model fits the data well for predicting mean speed on gravel roads.

Figure 5.3 Fit Diagnostics for Mean Speed Model



The model indicates that mean speeds on gravel roads do not have significant relationship with posted speed limit or ADT, while depending on road width, percent of large vehicles and surface classification. The estimated parameters for the independent variables could estimate the magnitude of such influences. As per the estimated model, mean speed would increase by 0.84 mph with 1 ft increase in road width, and increase by 0.11 mph with every one percent increase of large vehicles in total traffic. These relationships are very similar to those in the 85th-percentile speed model with some smaller increase rates. The model also shows that a sand-surfaced road probably has a 10.6 mph higher mean speed than a “G2” class road and a 9.0 higher mean speed than a “G1” class road. The R^2-value equals 0.4869, so this model can explain about 48.7% of the variation of the mean speeds on gravel roads.

85th-percentile speed is a more important term than mean speed in transporation engineering, as it is commonly accepted as a determinant element when setting a speed limit on a certain road. Whereas, a mean speed model was still fitted in this study, which was aimed at studying how a set of observed roadway characteristics affect traffic speeds on gravel roads and to what extent these effects are imposed. As per the two models, the four independent variables show quite similar effects in both models.

5.3 Results of Crash Data Collection

This section presents the crash data obtained from the KARS database, including annual crash frequencies in Kansas as well as number of crashes based on speed limits and two counties which are of interest.

5.3.1 Crash Trend on Kansas Gravel Roads

During the period of 1996 to 2005, more than 36,000 crashes have been reported on gravel roads in Kansas, accounting for nearly 5.5% of the total number of crashes during the same period. This is equivalent to about 10 crashes on Kansas gravel roads every day. Table 5.8 presents a summary of annual crash frequencies on gravel roads during the period 1996 to 2005. It can be seen that the total number of crashes reached the highest in 2003 and then deceased till 2005.

Table 5.9 presents the number of personal injuries for each year during the period 1996 to 2005. A general decreasing trend of the number of personal injuries can be found from the data.

Table 5.8 Crashes on Kansas Gravel Roads by Severity (1996-2005)

Year	Crash Frequencies by Severity					Total
	Fatal	Disabled	Non-Incapacitating	Possible	PDO	
1996	48	115	555	379	2,249	3,346
1997	32	108	555	413	2,564	3,672
1998	37	110	517	373	2,490	3,527
1999	43	103	493	418	2,550	3,607
2000	44	113	508	409	2,517	3,591
2001	37	124	524	465	2,670	3,820
2002	40	109	545	412	2,689	3,795
2003	39	113	505	406	2,817	3,880
2004	30	84	511	356	2,533	3,514
2005	33	109	527	382	2,294	3,345
Total	383	1,088	5,240	4,013	25,373	36,097

(Source: KARS, 2006)

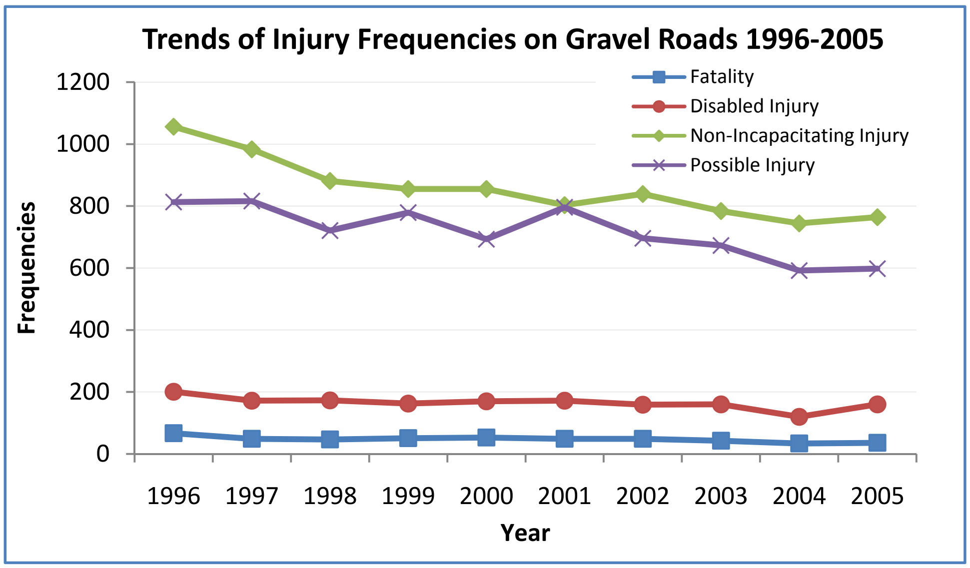
Table 5.9 Personal Injuries on Kansas Gravel Roads by Severity (1996-2005)

Year	Injury Frequencies by Severity				Total
	Fatal	Disabled	Non-Incapacitating	Possible	
1996	67	201	1,056	813	4,303
1997	49	172	983	816	4,566
1998	47	173	881	721	4,169
1999	51	163	855	779	4,224
2000	53	170	855	693	4,286
2001	49	172	803	796	4,258
2002	49	159	839	696	4,186
2003	43	160	784	673	4,258
2004	34	120	744	592	3,731
2005	36	160	764	598	3,578
Total	478	1650	8,564	7,177	41,559

(Source: KARS, 2006)

Figure 5.4 plots the data in Table 5.9 and shows the trends of injury frequencies based on severity from 1996 to 2005. It can be seen that the general trends of injuries for all levels of severity have a decreasing tendency. The non-incapacitating injuries have a much steeper slope than the other three severities. However, small increases can be found for all levels of personal injuries when comparing the 2005 data to 2004 data.

Figure 5.4 Trends of Injury Frequencies on Kansas Gravel Roads



5.3.2 Equivalent Economic Loss by Gravel Road Crashes

Even though the number of gravel road crashes is relatively small compared to the total number of crashes, the economic loss is significant. Table 5.10 describes the unit costs per personal injury by severity and PDO crash which have been used in Kansas from 2000 to 2005. The cost values refer to the actual dollar values in each corresponding year.

Based on Tables 5.9 and 5.10, annual equivalent economic loss due to gravel road crashes from 2000 to 2005 was calculated as shown in Table 5.11. It was found that the overall costs for each year from 2000 to 2005 all exceed 200 million dollars, which nearly equal 4,660 times the median household income of $42,920 in Kansas in 2005 (U.S. Census Bureau, 2007).

Table 5.10 Unit Costs Based on Personal Injuries and PDO Crashes in Kansas

Year	Cost Per Fatal Injury	Cost Per Disabling Injury	Cost Per Non-Disabling Injury	Cost Per Possible Injury	Cost Per PDO Accident
2000	$3,113,950	$215,600	$43,100	$22,750	$2,400
2001	$3,113,950	$215,600	$43,100	$22,750	$2,400
2002	$3,231,300	$223,700	$44,750	$23,600	$2,500
2003	$3,294,200	$228,050	$45,600	$24,050	$2,550
2004	$3,391,450	$234,800	$47,000	$24,800	$2,600
2005	$3,391,450	$234,800	$47,000	$24,800	$2,600

(Source: KDOT, Bureau of Transportation Planning, 2007)

Table 5.11 Equivalent Economic Loss by Gravel Road Crashes

Year	Economic Loss due to Gravel Road Crashes by Severity (Million Dollars)					Total
	Fatal	Disabled	Non-Incapacitating	Possible Injury	PDO	
2000	$165	$37	$37	$16	$7	$262
2001	$153	$37	$35	$18	$7	$250
2002	$158	$36	$38	$16	$7	$255
2003	$142	$36	$36	$16	$8	$238
2004	$115	$28	$35	$15	$7	$200
2005	$122	$38	$36	$15	$6	$217

5.3.4 Gravel Road Crashes Based on Speed Limits

Table 5.12 presents a contingency table which comprises of crash frequencies based on different severities of crashes and different values of speed limits on gravel roads in Kansas. It can be seen that crashes on 55 mph gravel roads account for the largest proportion, or 81.7%, of the total number of crashes. Gravel roads posted with 30 mph and 35 mph respectively rank the second and third highest position.

Table 5.12 Speed Limit versus Crash Severity for Kansas Gravel Road Crashes (96-05)

Factor	Category	Crash Severity					Total	Percent of Total
		Fatal	Disabled	Non-Incapacitating	Possible	PDO		
Speed Limit	30 mph	6	35	298	258	2,353	2,950	8.5%
	35 mph	12	57	306	183	1,336	1,894	5.5%
	40 mph	0	10	42	38	173	263	0.8%
	45 mph	9	33	148	107	684	981	2.8%
	50 mph	5	8	31	27	202	273	0.8%
	55 mph	347	919	4,291	3,296	19,530	28,383	81.7%
Total		379	1,062	5,116	3,909	24,278	34,744	100%
Percent of Total		1.1%	3.1%	14.7%	11.3%	69.9%	100%	

5.3.4 Gravel Road Crashes Based on County

Crash data in two counties of interest, Johnson and Smith Counties, were provided in this section, which are analyzed with statistical methods in the following section.

Table 5.13 lists the number of gravel road crashes based on severity for Johnson County and its four adjacent counties, Miami, Franklin, Leavenworth and Douglas Counties. All the adjacent counties have no posted speed limits on gravel roads and use the statutory speed limit of 55 mph.

Table 5.13 Gravel Road Crashes in Johnson and Adjacent Counties (96-05)

County	Crash Severity					Total
	Fatal	Disabled	Non-Incapacitating	Possible	Non-Injured	
Johnson	4	31	114	58	489	696
Miami	13	42	159	160	1,009	1,383
Franklin	12	58	163	124	698	1,055
Leavenworth	8	23	148	84	667	930
Douglas	3	22	181	102	809	1,117
Statewide	433	1,236	5,922	4,608	29,414	41,613

Based on crash frequencies and gravel road mileages in each county, crash rates can be estimated by dividing the number of crashes in each county by corresponding mileages. The formula used to estimate the Fatal Crash Rate (FCR) is as follows:

$$\text{Fatal Crash Rate (crashes/mile/year)} = \frac{\text{Number of Fatal Crashes}}{10 * \text{Gravel Road Mileage}}$$

The rates for other crash categories (i.e. Total-Crash Rate (TCR), Disabled-Crash Rate (DCR), Non-Incapacitating-Crash Rate (NCR), Possible-Crash Rate (PCR) and PDO-Crash Rate (PDO)) can be computed in a similar manner. The estimated crash rates for the selected counties are presented in Table 5.14. As estimated, almost all the crash rates, except for FCR, of Johnson County are higher than those of the other four counties. And all the rates of the five counties are much higher than the average statewide level.

Table 5.14 Estimated Crash Rates for Johnson and Adjacent Counties

County	Crash Rates by Severity (crashes/mile/year)					
	FCR	DCR	NCR	PCR	PDO	Overall
Johnson	0.0017	0.0132	0.049	0.025	0.209	0.297
Leavenworth	0.0018	0.0050	0.032	0.018	0.146	0.204
Miami	0.0019	0.0060	0.023	0.023	0.144	0.198
Douglas	0.0005	0.0039	0.032	0.018	0.142	0.196
Franklin	0.0013	0.0064	0.018	0.014	0.078	0.117
Statewide	0.0006	0.0016	0.008	0.006	0.038	0.053

The crash rates were also estimated for Smith County of Kansas and its adjacent counties. Smith County has posted gravel road speed limit at 45 mph, and no speed limit signs are used on gravel roads in its adjacent counties, Jewell, Osborne, Rooks and Philips Counties. Table 5.15 summarizes the crash frequencies and the estimated crash rates are presented in Table 5.16.

Table 5.15 Gravel Road Crashes in Smith and Adjacent Counties (1996-2005)

County	Crash Frequencies					
	Fatal	Disabled	Non-Incapacitating	Possible	PDO	Total
Smith	4	4	18	20	228	274
Jewell	2	13	34	22	272	343
Osborne	4	3	17	19	161	204
Rooks	1	14	27	30	244	316
Phillips	2	4	35	28	194	263

As Table 5.16 shows, the FCR of Smith County was a little bit higher than that of the other four counties except for Osborne, while Smith County had the lowest rates of the other four types of crashes and the lowest overall crash rate compared to its adjacent counties. It is also noticed that all the six rates of Smith County were lower than the average statewide level.

Table 5.16 Estimated Crash Rates for Smith and Adjacent Counties

County	Crash Rate by Severity (crashes/mile/year)					
	FCR	DCR	NCR	PCR	PDO	Overall
Osborne	0.0017	0.0013	0.0074	0.0083	0.0700	0.0887
Jewell	0.0004	0.0026	0.0068	0.0044	0.0546	0.0689
Rooks	0.0002	0.0028	0.0054	0.0060	0.0488	0.0632
Phillips	0.0003	0.0006	0.0057	0.0045	0.0313	0.0425
Smith	0.0005	0.0005	0.0024	0.0027	0.0304	0.0365
Statewide	0.0006	0.0016	0.008	0.006	0.038	0.053

5.4 Results of Crash Data Analyses

This section mainly introduces the results of the statistical studies which were performed to study the crash data presented in section 5.3. The subsection 5.4.1 summarizes the results of chi-square tests, and subsection 5.4.2 presents the results of logistic regression modeling which evaluate the effects of a set of contributing factors on the severity of gravel road crashes.

5.4.1 Results of Chi-Square Test

Chi-square tests were performed to test the independence of two variables, such as speed limit and crash severity. The null hypothesis is that the two variables are independent of each other. The existence of independence implies that the two variables are not affecting each other at a certain significance level. In this study, chi-square tests were conducted to study the effects of speed limit on severity of crashes which have been obtained from the KARS database.

Test #1 for the Overall Crash Data

First of all, the overall crash data on gravel roads were considered as shown in Table 5.12. Chi-square test was conducted using the SAS software, and the test results are presented in Table 5.17. Both X^2 and G^2 statistics give the p-value less than 0.0001, so the null hypothesis of independence is rejected, indicating that there is a significant relationship between speed limit and crash severity.

Since both variables are ordinal, the Mantel-Haenszel statistic (M^2) was used to test the existence of a linear relationship. The correlation coefficient (r) was estimated to be -0.0594. The test statistic M^2 is 122.687, giving a p-value less than 0.0001. So there is strong evidence that speed limit and crash severity are related. In other words, if treating speed limit as an explanatory variable and crash severity as a response, the chi-square test implies that the probability of having a crash in a certain severity level tends to change as speed limit on that gravel road changes. This effect was estimated by computing the odds ratio (θ statistic) and its 95% confidence interval (C.I.).

Table 5.17 Statistics of Chi-Square Test for Speed Limit versus Crash Severity

Statistics for Table of Speed Limit by Crash Severity

Statistic	DF	Value	Prob
Chi-Square	20	196.7332	<.0001
Likelihood Ratio Chi-Square	20	226.0109	<.0001
Mantel-Haenszel Chi-Square	1	122.6866	<.0001

Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	122.6866	<.0001

Pearson Correlation Coefficient

Correlation	-0.0594
ASE	0.0047
95% Lower Conf Limit	-0.0686
95% Upper Conf Limit	-0.0502

Test of H0: Correlation = 0

ASE under H0	0.0048
Z	-12.4273
One-sided Pr < Z	<.0001
Two-sided Pr > |Z|	<.0000

Table 5.18 is a retreated 2 × 2 contingency table, in which speed limits lower than 55 mph were combined into a new category "<55", and for crash severity, "Fatal" and "Disabled" were combined into "Severe" with the rest three categories combined into "Less Severe". The odds ratio was estimated at 0.6059 and its 95% C.I. did not include 1.0, indicating that 55 mph gravel roads had an approximately two times higher odds of having severe crashes that those gravel roads with lower speed limits. Since the probability of severe crashes is small, odds ratio is approximately the same as relative risk (Agresti, 2007). Therefore, the probability of having a severe crash is about two times higher on 55 mph gravel roads than on gravel roads with lower speed limits.

The finding here makes sense on a real-world perspective. For gravel roads, speed zones with lower limits like 35 and 40 mph are usually established on hazardous locations like curves and sites with limited sight distance. Drivers are expected to pay more attention to road situations when they are negotiating such locations, therefore causing the probability of suffering severe crashes to decrease.

Table 5.18 Odds Ratio for Speed Limit versus Crash Severity

Speed Limit (mph)	Crashes Based on Severity		Total
	Severe	Less Severe	
<55	175	6,186	6,361
55	1,266	27,117	28,383
Total	1,441	33,303	34,744
$\hat{\theta}$ = 0.6059, 95% C.I. = (0.5161, 0.7114)			

Note: $\hat{\theta}$ denotes odds ratio, and C.I. denotes confidence interval.

Test #2 for Johnson and Adjacent County Crash Data

The second chi-square test was conducted to test the independence of crash severity with county. The data are presented in Table 5.13. The crash data in the four counties adjacent to Johnson County (Miami, Leavenworth, Douglas and Franklin Counties) were combined to make a more meaningful comparison. The retreated crash data and the chi-square test results are presented in Table 5.19.

Based on the results, the p-values given by X^2 and G^2 statistics are both around 0.12, so there is no evidence to reject the null hypothesis. Therefore, the two variables, county and crash severity, are independent of each other. In other words, the probability of having a certain severity crash on gravel roads is the same for Johnson County and its adjacent counties, which implies the 35 mph speed limit posted on gravel roads in Johnson County did not cause crash characteristics to be different from those in adjacent counties.

Odds ratio is also estimated as shown in Table 5.20. Although the value for odds ratio is estimated to be 1.2591, the 95% C.I. includes 1.0, which indicates it is very possible that county and crash severity are independent. This result is consistent with what is found in the Chi-Square test.

Table 5.19 Crash Data and Chi-Square Test Results for Johnson and Adjacent Counties

County	Crashes Based on Severity					Total
	Fatal	Disabled	Non-Incapacitating	Possible	PDO	
Johnson	4	31	114	58	489	696
Adjacent	36	145	651	470	3,183	4,485
Total	40	176	765	528	3,672	5,181

Statistic	DF	Value	Prob
Chi-Square	4	7.2338	0.1240
Likelihood Ratio Chi-Square	4	7.1804	0.1267
Mantel-Haenszel Chi-Square	1	1.3454	0.2461
Phi Coefficient		0.0374	
Contingency Coefficient		0.0373	

Table 5.20 Retreated Crash Data and Estimated Odds Ratio

County	Crashes Based on Severity		Total
	Severe	Ordinary	
Johnson	35	661	696
Adjacent	181	4,304	4,485
Total	216	4,965	5,181
$\hat{\theta}$ = 1.2591, 95% C.I. = (0.8688, 1.8248)			

Test #3 for Smith County and Adjacent Counties Crash Data

The chi-square test results for crashes in Smith County and its adjoining counties (Osborne, Jewell, Rooks, and Phillips Counties) are presented in Table 5.21. In this test, both X^2 and G^2 statistics give very small p-values, respectively 0.0015 and 0.0003, indicating that the null hypothesis is rejected. In other words, Smith County and its adjoining counties have different crash distributions based on level of severity on gravel roads. This difference might be caused by a variety of factors. Since no other obvious influential factors could be observed, this effect can only be explained by the use of posted 45 mph speed limit on gravel roads in Smith County while adjacent counties set 55 mph as statutory speed limit without posting it.

Table 5.21 Retreated Crash Data and Chi-Square Test Statistics for Test #3

County	Crashes Based on Severity					Total
	Fatal	Disabled	Non-Incapacitating	Possible	PDO	
Smith	4	4	8	20	228	264
Adjacent	9	34	113	99	871	1,126
Total	13	38	121	119	1,099	1,390

Statistics of Chi-Square Test

Statistic	DF	Value	Prob
Chi-Square	4	17.5637	0.0015
Likelihood Ratio Chi-Square	4	20.8580	0.0003
Mantel-Haenszel Chi-Square	1	8.8760	0.0029
Phi Coefficient		0.1124	
Contingency Coefficient		0.1117	

Since the observed numbers of severe crashes are both very small for Smith and adjacent counties, the odds ratio method was not used for the data to avoid possible big standard error that might be caused due to the small number of observations.

5.4.2 Results of Logistic Regression

Logistic regression was applied to evaluate the impacts of speed limit as well as a group of other factors on predicting the probability of having a crash at a certain level of severity on gravel roads. Odds ratios were estimated to predict the quantitative effects of one-unit changes of explanatory variables on the change of the estimated probabilities for the outcome of the response variable (i.e. a certain level of severity for the ith observation). A total of four logistic regression models were fitted based on a descending order of crash severity which is shown in Table 5.22.

Table 5.22 Description of Response Variables in Four Logistic Models

Model	Response Variable	Description
1	FATAL	= 1 if the observation is a fatal crash, = 0 otherwise (i.e. disabled, non-incapacitating, possible or non-injured)
2	INCAP	=1 if the observation is a disabled crash, = 0 otherwise (i.e. non-incapacitating, possible or non-injured)
3	NON_INCAP	=1 if the observation is a non-incapacitating crash, = 0 otherwise (i.e. possible or non-injured)
4	POSSIBLE	=1 if the observation is a possible injured crash, = 0 otherwise (i.e. non-injured)

The candidate independent variables and their denotations used in logistic regression are shown in Table 5.23. All the variables except for SPEED_LIMIT are dummy variables, i.e., each variable takes only two values, either 0 or 1. Table 2.23 explains how the binary values, 0 and 1, are assigned to each dummy variable. The mean values are arithmetic average for each variable, and they can be interpreted as the proportions of total crashes which can be attributed to that corresponding variable. For example, variable ALCOHOL had a mean of 0.076, indicating that alcohol caused 7.6% of the total number of crashes. This study considered most of variables available in the KARS database, while there were still some not included due to lack of information or too few observations.

Speed limit is included as an independent variable to assess the effect of vehicle speeds on the severity of crashes on gravel roads. To be more accurate, travel speed at the time of accident should be considered for this purpose, but it is not available in the crash database. Therefore, speed limit is used as a surrogate measure, assuming motorists always travel complying with speed limits on gravel roads.

Table 5.23 Selected Candidate Variables for Logistic Regression Modeling

Variable	Mean	Standard Deviation	Description
TWO_VEH_CR	0.199	0.399	=1 if there were two vehicles involved, =0 elsewise
PED_INVL	0.002	0.045	=1 if there was pedestrian involved, =0 elsewise
ALCOHOL	0.076	0.265	=1 if there was an alcohol involvement, =0 elsewise
ON_RDW	0.872	0.334	=1 if the crash occurred on a roadway, =0 elsewise
SPEED_LIMIT	50.381	9.633	Speed limit in mph
LIGHT_CON	0.391	0.488	=1 if the crash happened in dark or unlit conditions, =0 elsewise
WTH_CON	0.904	0.295	=1 if there was no adverse weather conditions, =0 elsewise
SLP_RD_SURF	0.182	0.386	=1 if road surface was slippery, =0 elsewise
RD_CHAR	0.566	0.496	=1 if the road was straight and level, =0 elsewise
OVERTURNED	0.168	0.374	=1 if it was an overturned crash, =0 elsewise
VEH_ANM	0.191	0.393	=1 if the vehicle collided with an animal, =0 elsewise
VEH_FXD_OBJ	0.408	0.491	=1 if the vehicle collided with a fixed object, =0 elsewise
HDON	0.017	0.130	=1 if it was a head-on crash, =0 elsewise
REAR_END	0.027	0.161	=1 if it was a rear-end crash, =0 elsewise
ANGLE_SIDE	0.106	0.308	=1 if it was an angle-side crash, =0 elsewise
SIDEWIPE	0.027	0.162	=1 if it was a side-wipe crash, =0 elsewise
BACK_INTO	0.016	0.126	=1 if it was a backed-into crash, =0 elsewise
DR_OLD	0.111	0.314	=1 if at least one involved driver was older than 65, =0 elsewise
DR_YOUNG	0.531	0.499	=1 if one involved driver was younger than 25, =0 elsewise
DR_GENDER	0.591	0.492	=1 if one driver was male for single-veh crash or both drivers were male for two-veh crashes, =0 elsewise
SAFE_EQMT_USE	0.273	0.445	=1 if one driver did not use safety equipment, =0 elsewise
DR_EJECT	0.029	0.167	=1 if one driver was ejected or partially ejected, =0 elsewise
DR_FAIL_ROW	0.072	0.259	=1 if the driver failed to yield right-of-way, =0 elsewise
DR_DISR_TCD	0.022	0.147	=1 if due to disregarding traffic signs, signals, =0 elsewise
DR_EXCD_SL	0.027	0.162	=1 if the driver exceeded posted speed limit, =0 elsewise
DR_TOO_FAST	0.314	0.464	=1 if the driver drove too fast for conditions, =0 elsewise
DR_INATTN	0.347	0.476	=1 if the crash was due to the driver's inattention, =0 elsewise
DR_AV/EV_ACT	0.070	0.255	=1 if the driver had avoidance or evasive action, =0 elsewise
RD_RUT	0.027	0.162	=1 if the roadway had ruts, holes or bumps, =0 elsewise

Model for Fatal Crashes

The estimated parameters and related statistics of the logistic model for fatal crashes on gravel roads are shown in Table 5.24. Based on the model fit statistics, the *AIC, SC, and -2 Log L* statistics show very significant decrease for the fitted model with those important explanatory variables compared to the model which has intercept only, suggesting an appropriate fit of this model. The Hosmer-Lemeshow test has a chi-squared value of 8.139 and gives a p-value of 0.5202. Therefore, the goodness-of-fit of this model is verified. The adjusted R^2 is 0.3626. In addition, the test for the global null hypothesis that all parameter equal zero was strongly rejected since the estimated likelihood-ratio statistic is very high for chi-square distribution with degree of freedom of 12.

Based on Table 5.24, a total of 12 variables, including SPEED_LIMIT, were identified as important predictors in the fitted logistic model with 90% confidence. The estimated parameter for the variable speed limit is 0.038 with an estimated stand error of 0.0101, which indicates that the risk of being a fatal crash for the *i*th observation tends to increase as speed limit increases. The quantitative extent of this affection can be estimated by calculating the odds ratio which is shown in the rightmost column of Table 5.24. As per the estimated odds ratio of 1.039 for speed limit, the odds for the *i*th observation to be a fatal crash tend to increase 3.9% as speed limit increases by one unit (i.e. 1 mph). Since the minimum interval for setting speed limits is 5 mph, the increment of the odds observing a fatal crash for each 5 mph increment in speed limit, when holding other variables constant, can be estimated as follows:

$$\Delta\theta \ = [(1 + 3.9\%)^5 - 1] \times 100\% = 21.1\%$$

For example, when all the other 11 variables are held at their means, the probability of observing a fatal crash for 45 mph speed limit is 0.473% with the odds of 0.00475, and the probability increases to 0.571% when speed limit is raised up to 50 mph, giving the odds of 0.00574. The increase rate of the odds as speed limit is raised from 45 mph to 50 mph is 21.1%, as estimated by $\Delta\theta$.

Table 5.24 Estimated Logistic Regression Parameters for Fatal Crashes on Gravel Roads

Variable	Estimated Parameter	Standard Error	Wald Chi-Square	p-value (Pr > ChiSq)	Odds Ratio
INTERCEPT	-6.762	0.9093	55.31	<.0001	-
ALCOHOL	0.469	0.0825	32.33	<.0001	1.598
ON_RDW	-0.275	0.0878	9.78	0.0018	0.760
SPEED_LIMIT	0.038	0.0101	14.05	0.0002	1.039
VEH_ANM	-1.435	0.5073	8.01	0.0047	0.238
VEH_FXD_OBJ	-0.201	0.0788	6.47	0.0110	0.818
SIDEWIPE	-1.019	0.5069	4.04	0.0444	0.361
DR_OLD	0.29	0.1028	7.95	0.0048	1.336
DR_YOUNG	-0.186	0.0729	6.54	0.0106	0.830
SAFE_EQMT_USE	0.85	0.0990	73.76	<.0001	2.340
DR_EJECT	1.419	0.0756	352.54	<.0001	4.133
DR_FAIL_ROW	0.379	0.1023	13.71	0.0002	1.461
DR_INATTN	0.144	0.0693	4.31	0.0378	1.155

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	2782.339	1845.438
SC	2790.172	1947.264
-2 Log L	2780.339	1819.438

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	960.9011	12	<.0001
Score	2713.8381	12	<.0001
Wald	768.4386	12	<.0001

Hosmer and Lemeshow Goodness-of-Fit Test

Chi-Square	DF	Pr > ChiSq
8.1390	9	0.5202

Adjusted R^2 = 0.3626

The model also reveals some other significant variables which might cause the risk of fatal crashes to increase. They are alcohol involvement, old drivers, not using safety equipment, driver ejection, failure to yield the right-of-way, and driver inattention. It is noticed that the odds for a crash with driver ejected to be a fatal crash is more than 4 times the odds when driver is not ejected. Not using safety equipment also tends to raise the odds of observing a fatal crash to 2.3 times higher than using safety equipment.

Model for Disabled Crashes

Table 5.25 shows the estimated regression parameters and statistics for disabled crashes on gravel roads. The global null hypothesis test indicates the parameters for the covariates in the model are significantly important. The three model fit statistics and the HL-test indicates the goodness-of-fit of the fitted model. The adjusted R^2 value is 0.2115, relatively lower than that of the fatal crash model. A total of eleven variables entered the final model with 90% confidence, eight of which have positive parameters indicating positive relationships with the probability of having a disabled crash. The parameter for speed limit is 0.026, giving an odds ratio of 1.024. Therefore, the odds for the probability of observing a disabled crash increase by 12.6% for every 5 mph increase in speed limit while holding other variables constant. Driving behaviors, like exceeding speed limit and too fast for conditions, were also observed to be significantly important in causing higher risk of disabled crashes.

Table 5.25 Estimated Logistic Regression Parameters for Disabled Crashes

Variable	Estimated Parameter	Standard Error	Wald Chi-Square	p-value (Pr > ChiSq)	Odds Ratio
INTERCEPT	-4.216	0.4355	93.67	<.0001	0.015
ALCOHOL	0.336	0.0540	39.11	<.0001	1.402
SPEED_LIMIT	0.026	0.00496	23.28	<.0001	1.024
SLP_RD_SURF	-0.204	0.0622	10.73	0.0011	0.816
VEH_ANM	-1.19	0.1929	38.08	<.0001	0.304
HDON	0.558	0.0950	34.46	<.0001	1.747
SIDEWIPE	-0.898	0.2560	12.30	0.0005	0.407
SAFE_EQMT_USE	0.608	0.0450	182.06	<.0001	1.836
DR_EJECT	0.992	0.0615	260.33	<.0001	2.695
DR_FAIL_ROW	0.403	0.0641	39.65	<.0001	1.497
DR_EXCD_SL	0.279	0.0878	10.09	0.0015	1.321
DR_TOO_FAST	0.193	0.0433	19.77	<.0001	1.213

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	5929.947	4848.078
SC	5937.766	4941.900
-2 Log L	5927.947	4824.078

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	1103.8689	11	<.0001
Score	1804.7213	11	<.0001
Wald	927.1486	11	<.0001

Hosmer and Lemeshow Goodness-of-Fit Test

Chi-Square	DF	Pr > ChiSq
12.8012	8	0.1189

Adjusted $R^2 = 0.2115$

Model for Non-Incapacitating Crashes

Table 5.26 summarizes the estimated parameters for the logistic regression of non-incapacitating crashes on gravel roads. Though the values of three model fit statistics are very high, the goodness-of-fit of this model is still verified by the HL-test with a p-value of 0.0530. The parameter for speed limit is 0.019, implying that the probability of having a non-incapacitating crash increases as speed limit increases. The odds ratio for speed limit is estimated at 1.019, so each 1 mph increase in speed limit tends to cause the odds of having a non-incapacitating crash to increase by 1.9%. For each increment at the 5 mph interval, the estimated rate of increase for the odds of having a non-incapacitating crash is about 10%.

In the fitted model, a total of 21 variables are found to be significantly influential on predicting the probability of non-incapacitating crashes on gravel roads. 15 variables have positive parameters, indicating that the existences of these situations tend to increase the probability of having a non-incapacitating crash on any given site. It has been noticed that four types of behaviors with respect to drivers were observed to be very critical for resulting in non-incapacitating crashes, including exceeding speed limit, driving too fast for conditions, failure to yield right-of-way, and disregarding traffic control devices. Driving exceeding speed limits or too fast for conditions respectively tends to increase the odds of the probability of having a non-incapacitating crash by more than 20%, compared to driving under speed limits and consistent with actual conditions.

Table 5.26 Estimated Logistic Regression Parameters for Non-Incapacitating Crashes

Variable	Estimated Parameter	Standard Error	Wald Chi-Square	p-value (Pr > ChiSq)	Odds Ratio
INTERCEPT	-1.309	0.4446	8.67	0.0032	0.270
PED_INVL	1.28	0.1906	45.12	<.0001	3.596
ALCOHOL	0.289	0.0351	67.84	<.0001	1.335
ON_RDW	-0.08	0.0285	7.80	0.0052	0.923
SPEED_LIMIT	0.019	0.00242	63.44	<.0001	1.019
SLP_RD_SURF	-0.208	0.0292	50.67	<.0001	0.812
OVERTURNED	0.408	0.0417	95.83	<.0001	1.504
VEH_ANM	-1.107	0.0843	172.58	<.0001	0.331
VEH_FXD_OBJ	0.262	0.0382	47.16	<.0001	1.300
HDON	0.382	0.0755	25.54	<.0001	1.465
SIDEWIPE	-0.485	0.0931	27.19	<.0001	0.616
BACK_INTO	-1.288	0.2925	19.40	<.0001	0.276
DR_OLD	0.084	0.0396	4.45	0.0349	1.087
DR_YOUNG	0.059	0.0231	6.63	0.0100	1.061
DR_GENDER	-0.135	0.0218	38.50	<.0001	0.873
SAFE_EQMT_USE	0.467	0.0225	429.86	<.0001	1.595
DR_EJECT	0.93	0.0831	125.06	<.0001	2.534
DR_FAIL_ROW	0.263	0.0481	29.81	<.0001	1.300
DR_DISR_TCD	0.192	0.0636	9.07	0.0026	1.211
DR_EXCD_SL	0.185	0.0572	10.49	0.0012	1.203
DR_TOO_FAST	0.2	0.0225	79.61	<.0001	1.222
RD_RUT	0.275	0.1107	6.14	0.0132	1.316

Model Fit Statistics

Criterion	Intercept Only	Intercept and Covariates
AIC	17030.741	14133.371
SC	17038.521	14304.526
-2 Log L	17028.741	14089.371

Testing Global Null Hypothesis: BETA=0

Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	2939.3705	21	<.0001
Wald	1713.5790	21	<.0001

Hosmer and Lemeshow Goodness-of-Fit Test

Chi-Square	DF	Pr > ChiSq
15.9541	8	0.0530

Adjusted $R^2 = 0.2478$

Model for Possible (Injury) Crashes

As per the results summary of the logistic regression model in Table 5.27, increasing speed limit tends to increase the possibility of having possible injury crashes on gravel roads. Based on the odds ratio, every 5mph increment of speed limit tends to increase the odds of having a possible injury crash by 8.8%.

Table 5.27 Estimated Logistic Regression Parameters for Possible (Injured) Crashes

Variable	Estimated Parameter	Standard Error	Wald Chi-Square	p-value (Pr > ChiSq)	Odds Ratio
INTERCEPT	0.02	0.5731	0.001	0.9724	1.020
TWO_VEH	0.289	0.0966	8.98	0.0027	1.336
PED_INVL	2.533	0.4043	39.27	<.0001	12.597
ALCOHOL	0.153	0.0498	9.42	0.0021	1.165
SPEED_LIMIT	0.017	0.00281	37.31	<.0001	1.017
LIGHT_CON	-0.086	0.0290	8.74	0.0031	0.918
SLP_RD_SURF	-0.174	0.0341	26.17	<.0001	0.840
OVERTURNED	0.748	0.0933	64.40	<.0001	2.114
VEH_ANM	-0.701	0.1166	36.15	<.0001	0.496
VEH_FXD_OBJ	0.551	0.0906	36.96	<.0001	1.735
SIDEWIPE	-0.312	0.0897	12.06	0.0005	0.732
BACK_INTO	-1.271	0.2683	22.43	<.0001	0.281
DR_OLD	0.132	0.0455	8.40	0.0038	1.141
DR_YOUNG	0.06	0.0277	4.73	0.0297	1.062
DR_GENDER	-0.289	0.0260	123.14	<.0001	0.749
SAFE_EQMT_USE	0.356	0.0286	154.71	<.0001	1.427
DR_EJECT	0.808	0.1486	29.52	<.0001	2.243
DR_FAIL_ROW	0.207	0.0574	13.00	0.0003	1.230
DR_EXCD_SL	0.237	0.0719	10.84	0.0010	1.267
DR_TOO_FAST	0.146	0.0275	27.98	<.0001	1.157
DR_INATTN	0.097	0.0264	13.56	0.0002	1.102
RD_RUT	0.273	0.1357	4.04	0.0443	1.314

Hosmer and Lemeshow Goodness-of-Fit Test

Chi-Square	DF	Pr > ChiSq
2.9029	8	0.9403

Adjusted $R^2 = 0.2023$

All fours logistic regression models show that changing speed limit does have impacts on the probability of observing a motor crash at a certain level of severity on gravel roads. This type of effects tends to increase as crash severity increases based on the estimated values of the four models. It is implied that gravel roads have bigger probability to suffer severe crashes when speed limits go up, i.e., 21.1% for fatal crash, 12.8 for disabled crash, 10% for non-incapacitating crash, and 8.8% for possible injured crashes for every 5 mph increase in speed limit.

In the previous discussion in Section 5.4.1, it has been verified by studying crash data in Johnson and adjacent counties that the use of a lower speed limit on gravel roads has no effects on crash distributions based on severity. Actually, this finding does not violate the results from logistic regression modeling because the logistic regression was conducted based on the total crash data of the whole state. The crash data of Johnson County accounts for a very small portion, less than 1.7%, of total data, so it won't affect the validity of the results estimated from logistic regression.

CHAPTER 6 - Summary of Surveys

This chapter describes the results of the traffic professional and road user surveys which have been conducted in Kansas. Section 6.1 presents the results of the traffic professional survey by discussing the general characteristics related to gravel roads in Kansas and current usage of speed limits in those responding counties as well as the opinions and comments regarding speed limit related issues on gravel roads. Section 6.2 summarizes the results of the road user survey.

6.1 Results of Traffic Professional Survey

All the 105 counties in Kansas were contacted. A total of 82 counties responded, in which eighty counties sent back completed survey forms, one provided uncompleted survey and one was unable to answer the questions since there are no gravel roads in that county. The response rate for this survey is 78.1%. A sample survey form is provided in Appendix A.

The survey form consists of two parts:

a) Part I concerning general information about gravel roads (questions 1 through 5), and

b) Part II concerning specific issues about speed limit on gravel roads (questions 6 through 13)

6.1.1 General Information

Questions 1 to 5 of the survey gather basic information of gravel roads in each county, including mileage and percentage based on different situations, maintenance frequency, funds, materials used as surface and the resources.

The gravel road mileages in each county have been presented in Table 1.2 in Chapter 1. In the total length of gravel roads, 68.7% are county gravel roads and 31.3% are township roads. Based on the survey, as shown in Figure 6.1, 56.9% of gravel roads have very small amount of ruts, corrugations and potholes on the road surfaces, 29.1% have moderate amount and 14% have large amount of surface damages.

Figure 6.1 Proportion of Gravel Roads Based on Level of Surface Damages

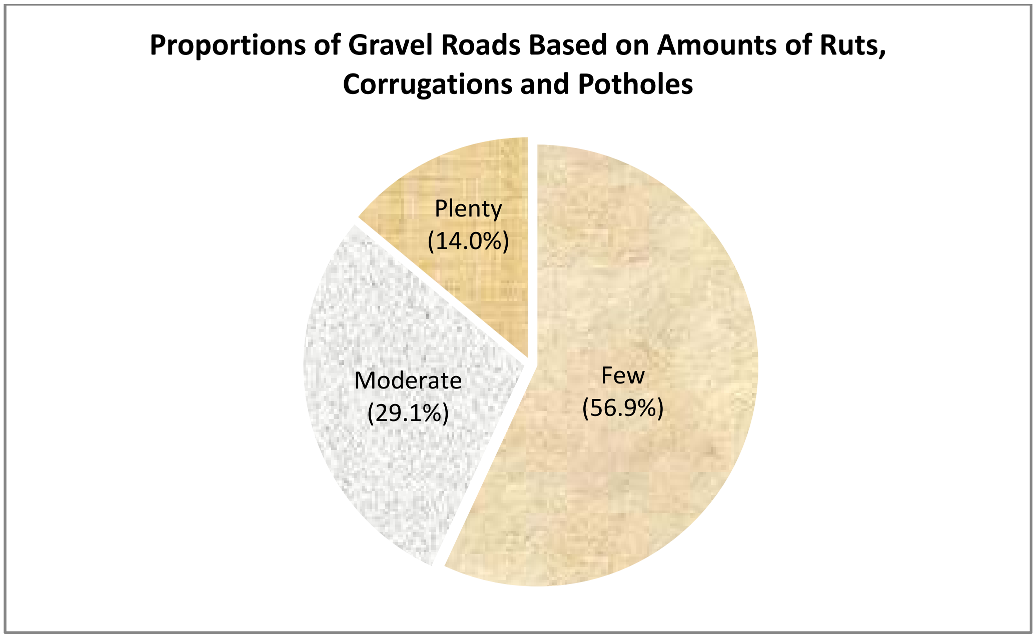
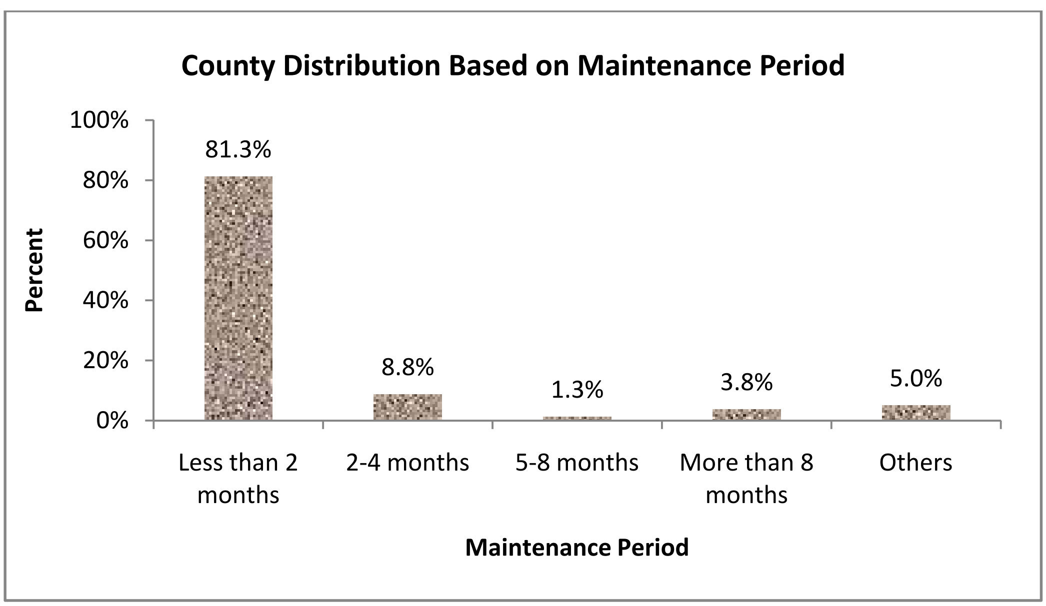


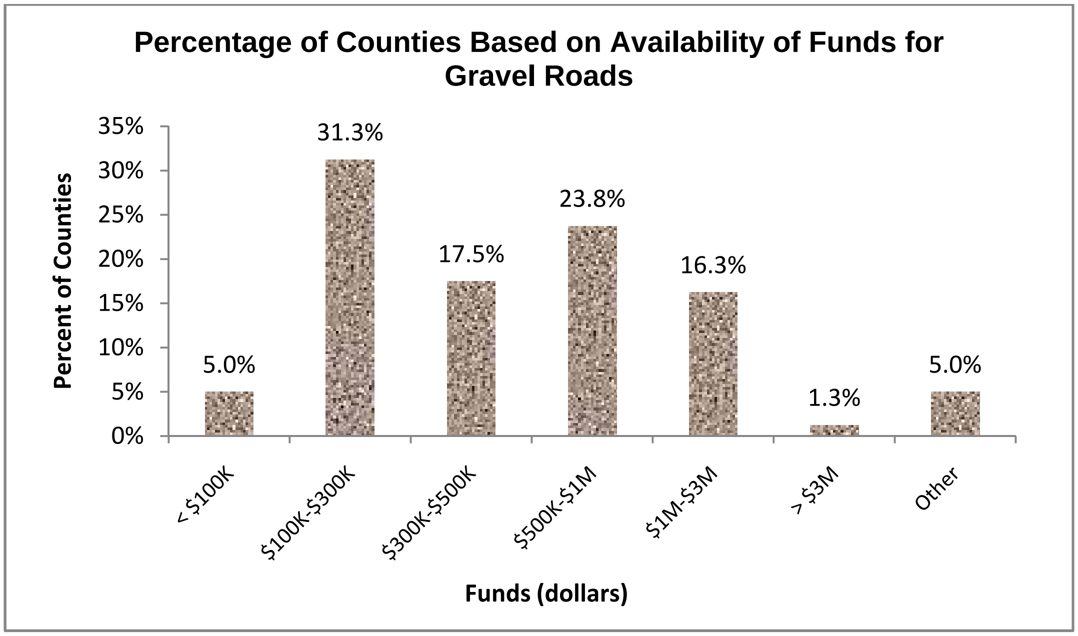
Figure 6.2 shows the percentage of counties based on how frequently the gravel roads are maintained. About 81% of the counties maintain their gravel roads at least once every two months, 8.8% maintain once every 2 to 4 months, 5% maintain at a period of over 5 months, and the remaining 5% maintain their gravel roads based on other conditions, like moisture, traffic, road conditions or when maintenance is needed.

Figure 6.2 Distribution of Counties Based on Maintenance Frequency on Gravel Roads



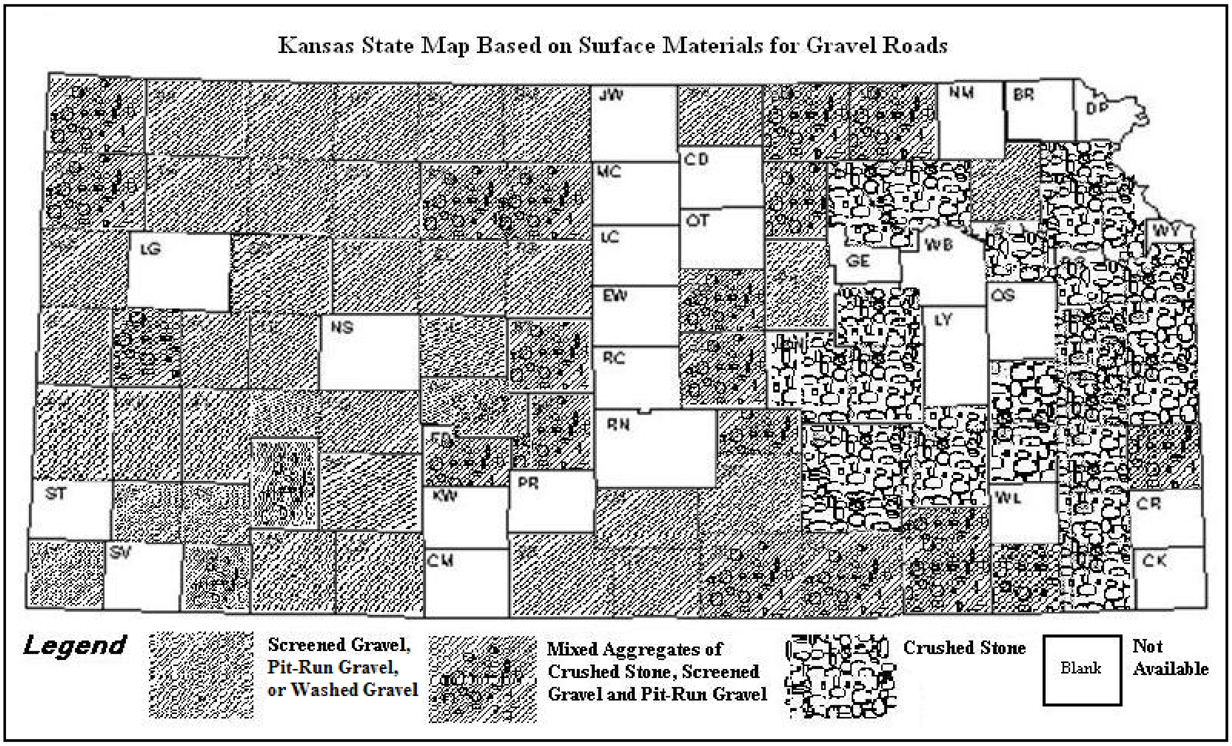
Annual available funds for gravel road maintenance are classified as six categories. The percentage of counties falling into each category is plotted in Figure 6.3. It can be seen that 31.3% of the counties have available annual funds in the range of $100K to $300K, 23.8% have $500K to $1M, and 17.5% have $300K to $500K. 17.6% of the counties have funds in excess of $1M, and about 5% have less than $100K for gravel road maintenance.

Figure 6.3 Percentage of Counties Based on Funds Available for Maintaining Gravel Roads



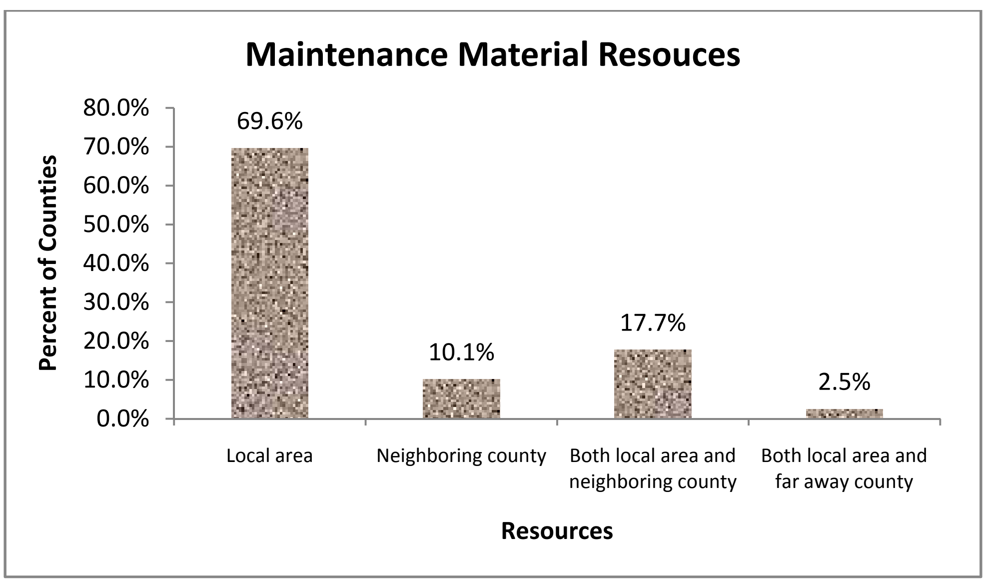
The fourth question on what types of surface materials used for gravel road maintenance indicated that 44.3% of the counties are using screened gravel, pit-run gravel or washed gravel, 25.3% use crushed gravel (crushed stone), and the rest 30.4% use a mixture of the mentioned materials. The map describing the distribution of material utilization in Kansas is shown in Figure 6.4. It is seen that most of the counties in the western part of Kansas use finer materials like screened or pit-run gravels while the majority of the counties in the eastern part of Kansas use larger gravels like crushed stones or aggregate mix for gravel road maintenance.

Figure 6.4 Utilization of Surface Materials for Gravel Road Maintenance in Kansas



About 70% of the responding counties use maintenance materials directly from local areas, and some have their own quarries. 10% need to purchase materials from neighboring counties. 17.7% use the materials both from local area and neighboring counties, and 2.5% use the materials both from local area and far away counties, as shown in Figure 6.5.

Figure 6.5 County Distribution Based on Maintenance Material Resources

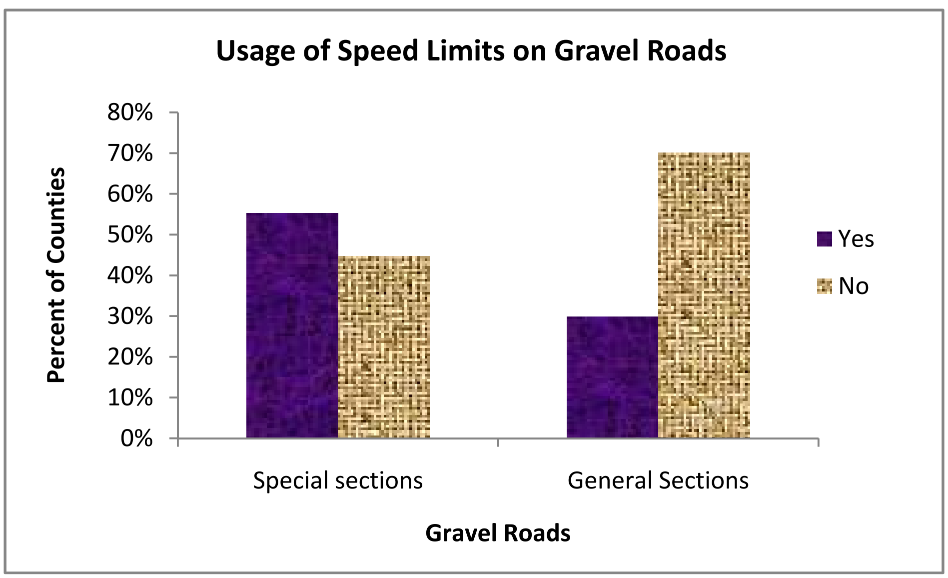


6.1.2 Regarding Speed Limits on Gravel Roads

This subsection describes the part II of the survey form regarding speed limits on gravel roads, which were based on Questions 6 through 13. 80 completed surveys were used for analysis in this part.

Figure 6.6 shows the percentage of counties based on usage of speed limits on gravel roads. 55.3% of the total responding counties post speed limits on special sections on gravel roads, such as curves, bridges, etc. About 30% answered they use speed limits on general sections on gravel roads. However, according to the respondents' input in the miles of gravel road which have speed limits, there are obviously not that many counties using speed limits on general sections. Actually, only Johnson County and Smith County have posted all their gravel roads at 35 mph and 45 mph respectively, and Leavenworth County posted about half of their gravel roads at 35 mph. Some other counties said they have tens of miles of gravel roads which have speed limits usually at some small values like 30, 35 or 40 mph.

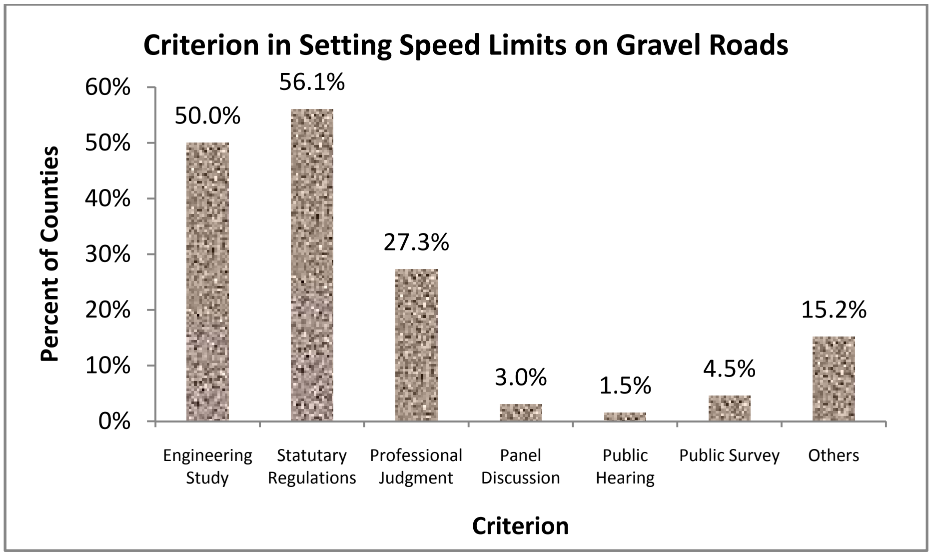
Figure 6.6 Usage of Speed Limits on Gravel Roads



The criteria used by each county in setting speed limits on gravel roads are requested to using multiple choice format. A total of 76 counties responded to this question, as shown in Figure 6.7. 50% of the counties set speed limits based on engineering study, 56% refer to statutory regulations (i.e. blanket speed limit), 27.3% use professional judgment, and less than 5% conduct panel discussion, public hearing or public survey to make a determination. Another

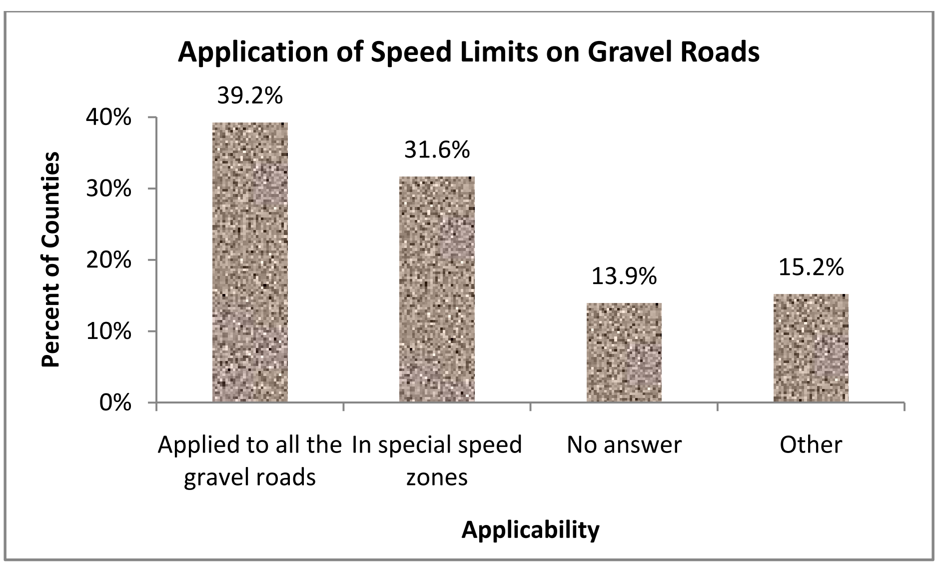
15% gave other answers, such as “do not set speed limits”, “driver judgment”, “resolution by county commissioners” and so on.

Figure 6.7 Criterion Used in Setting Speed Limits on Gravel Roads



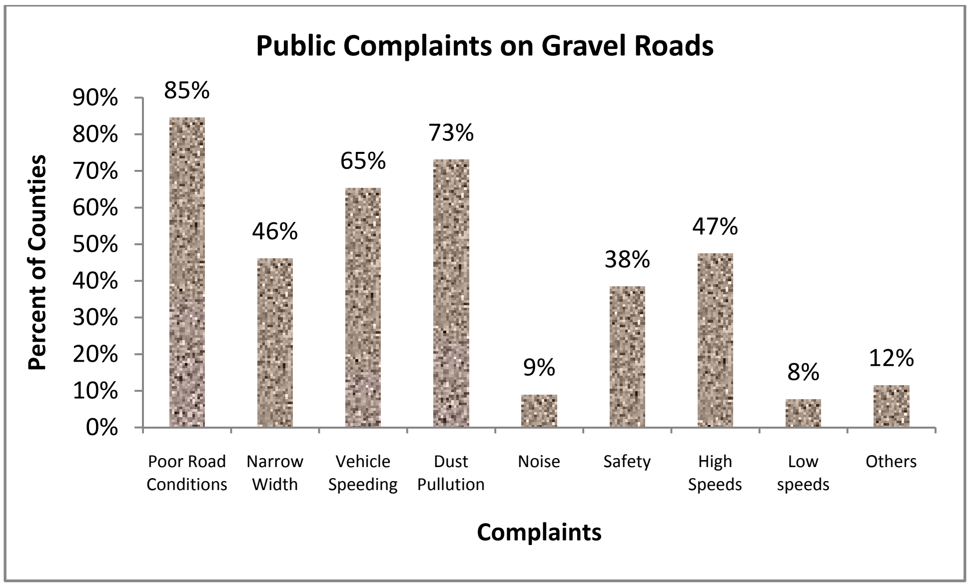
The application of speed limits on gravel roads in each county are shown in Figure 6.8. About 39% of the counties said the statutory speed limit (i.e., 55 mph) are applied to all the gravel roads, 31.6% answered that special speed zones are used, 14% did not answer this question, and 15% gave other answers, such as “resolution by county commissioners”, “no limit are used” and so on.

Figure 6.8 Application of Speed Limits on Gravel Roads



It is aware that all the responding counties have received many kinds of complaints from citizens regarding grave roads related issues. As shown in Figure 6.9, 85% of total counties have received complaints about poor road conditions, and 73% have complaints on dust pollution. Complaints regarding vehicle speeding and too high traffic speeds were received by 65% and 47% of the total counties respectively, and citizens in 38% of the counties worried about the safety on gravel roads.

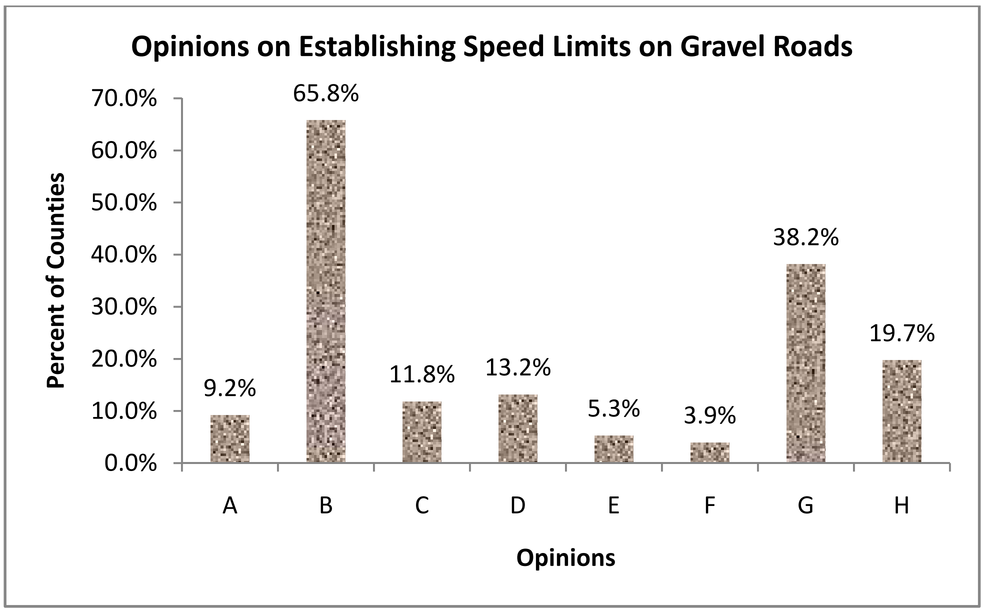
Figure 6.9 Public Complaints on Gravel Roads



Question 11 in the survey inquired the opinions of traffic professionals towards establishing speed limits on gravel roads. The results are shown in Figure 6.10. The sum of percentages in each column does not equal 100% since there could be multiple answers. 75% of total counties supported the use of blanket speed limit for gravel roads, and 88% of the blanket speed limit supporters did not suggest posting speed limit signs on roads. Among those who are in favor of blanket speed limit, as shown in Figure 6.11, 36.8% preferred a lower value as the speed limit, 8.8% claimed that the current 55 mph is satisfactory, 5.3% would like a higher value than 55 mph, and the other 49.1% did not express preferences on where blanket speed limit should be set. Only 11.8% of total respondents answered that speed zones could be used on gravel roads, while 56% of them were supporters for using blanket speed limit at the meantime. A few supporters (13.2% of total) for using blanket speed limit said that only some gravel roads need to have speed limit signs while the rest do not need. 5.3% said blanket speed limit do not contribute to traffic safety on gravel roads. 19.7% specified other answers as follows:

- Advisory speed posted on curves, regulatory speed posted through small towns, all other areas unposted but set as 55 mph or according to road conditions.
- Setting speed limit depends on the amount of traffic and road conditions.
- Do not use speed limit except for temporary purposes due to the constantly changing conditions of gravel roads.

Figure 6.10 Traffic Professionals' Opinions on Establishing Speed Limits on Gravel Roads



A = Should use blanket speed limit on gravel roads and the signs need to be posted.

B = Should use blanket speed limit on gravel roads and there is no need to post speed limit signs.

C = Prefer speed zones on some gravel roads because they work better than blanket speed limits.

D = Only some gravel roads need to have speed limits and the rest do not need.

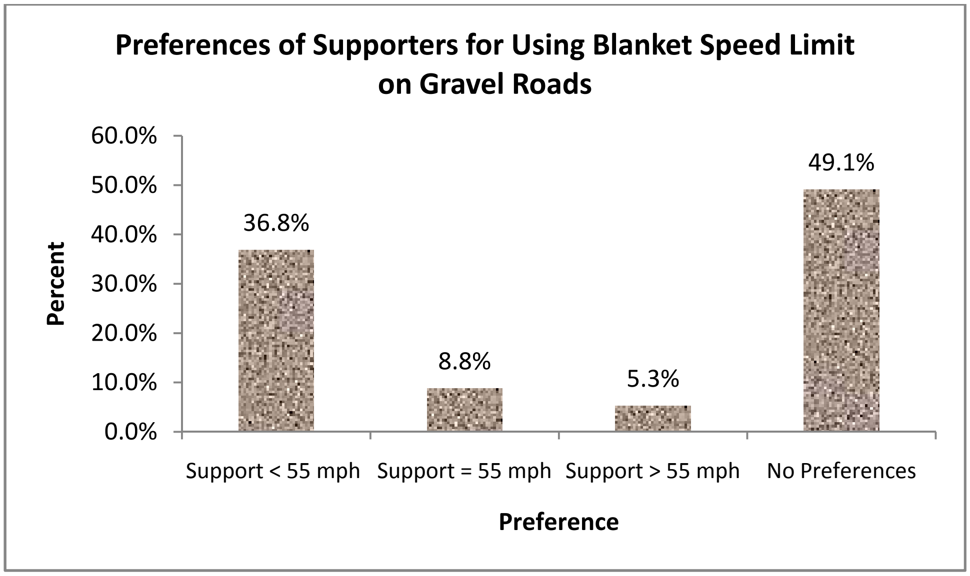
E = A blanket speed limit for gravel roads does not contribute to traffic safety.

F = I prefer a higher speed limit than 55 mph on gravel roads.

G = I prefer a lower speed limit than 55 mph on gravel roads.

H = Other (to be specified)

Figure 6.11 Preferences on Setting the Blanket Speed Limits Value



Question 12 listed a group of possibly important factors when establishing speed limits on gravel roads for the respondents to rank based on level of importance. Four levels of importance were assumed, which were in the order of high, moderate, low and no importance. A total of 74 answers are valid and used for analysis. As shown in Table 6.1, a positive 3 score is added for every ranking of "High" importance, a positive 1 score is for each "Moderate" importance, 0 is for each "Low" and a minus 3 score is added for each "None" importance. Based on the total scores, "surface condition", with a score of 164, is ranked as the most important factor of the thirteen factors which might be considered when establishing speed limits on gravel roads. It is followed by sight distance (score = 159) and accident history (score = 135). Statutory regulation ranks the 8th position with 39% respondents considering it is highly important. 27% of the respondents said 85th-percentile speed ranked in the 9th position is highly important, and 40.5% considered it as moderately important. Only 11% of respondents said public attitudes are highly important, and 7% selected it as not important.

The survey also welcomed related comments on the acceptability of current criteria used in setting speed limit on gravel roads. 36 counties (45%) gave important comments regarding this issue.

These comments can be roughly generalized into two groups:

A – neither change the blanket speed limit nor post speed limit signs on gravel roads

B – adopt a lower blanket speed limit (8.6%).

66% of the respondents who gave comments stand for A, implying that the majority of the county engineers are not willing to change current situations of speed limits on gravel roads, which can be attributed by the follow three facets based on these comments:

- The changeful conditions of gravel roads as weather and other conditions change (37.1%).
- The enforcement of speed limits on gravel roads is not practical (23%).
- It is too expensive to post speed limit sign on gravel roads (6%).

The supporters for B suggested that lower blanket speed limits (i.e. 40 or 45 mph) be adopted for gravel roads and only post those portions which should be traveled at less than the blanket speed limit.

Table 6.1 Rank of Possible Factors on Establishing Speed Limits on Gravel Roads

Factor	Level of Importance								Total Score
	High (+3)		Moderate (+1)		Low (0)		None (-3)		
	No.	%	No.	%	No.	%	No.	%	
Surface Condition	50	67.6%	17	23.0%	3	4.1%	1	1.4%	164
Sight Distance	47	63.5%	21	28.4%	3	4.1%	1	1.4%	159
Accident History	40	54.1%	21	28.4%	7	9.5%	2	2.7%	135
Road Damage by Heavy Vehicles	38	51.4%	22	29.7%	6	8.1%	2	2.7%	130
Road Width	30	40.5%	33	44.6%	4	5.4%	1	1.4%	120
Curvature	29	39.2%	33	44.6%	5	6.8%	1	1.4%	117
Traffic Volume	29	39.2%	30	40.5%	10	13.5%	1	1.4%	114
Statutory Regulation	29	39.2%	28	37.8%	8	10.8%	3	4.1%	106
85th-Percentile Speed	20	27.0%	30	40.5%	12	16.2%	3	4.1%	81
Maintenance Period	16	21.6%	38	51.4%	11	14.9%	4	5.4%	74
Roadside Development	13	17.6%	37	50.0%	17	23.0%	2	2.7%	70
Public Attitudes	8	10.8%	31	41.9%	23	31.1%	5	6.8%	40
Road Length	7	9.5%	26	35.1%	30	40.5%	5	6.8%	32

6.2 Results of Road User Survey

This section presents the results of the road user survey which was conducted in seven counties in Kansas, including Johnson, Miami, Leavenworth, Franklin, Smith, Douglas and Riley. The addresses of the road users were randomly picked out using the internet, based on the names of the gravel roads. A total of 840 mail-back surveys were sent out and 348 responses were returned indicating a 41.4% feedback rate. A sample of the road user survey form is provided in Appendix B.

6.2.1 General Characteristics of Respondents

General characteristics about the respondents include gender, age group, household income, driving age and awareness of gravel roads in Kansas, etc. As shown in Figure 6.12, male and female respondents account for 62.1% and 33% of the total, respectively.

Figure 6.12 Gender Proportions of Survey Respondents

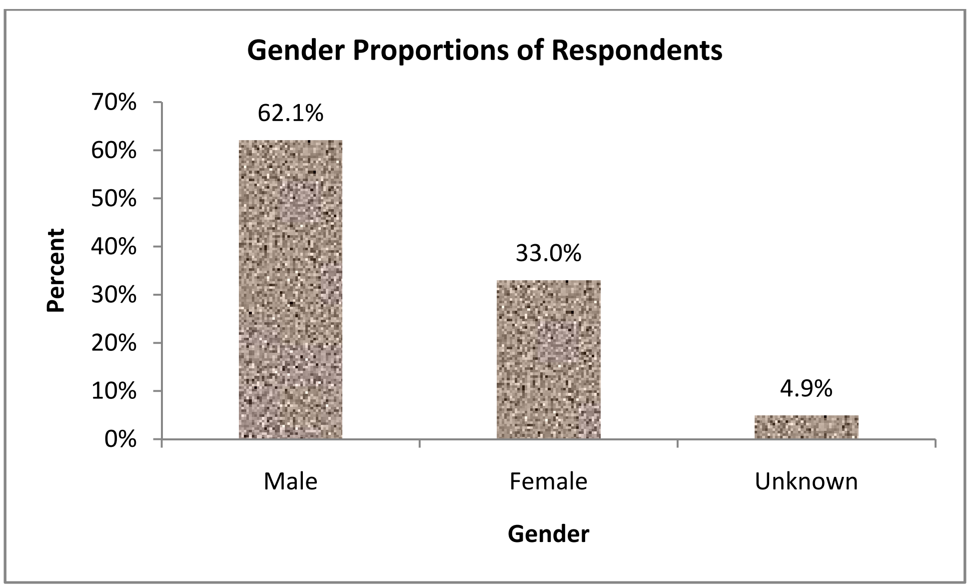
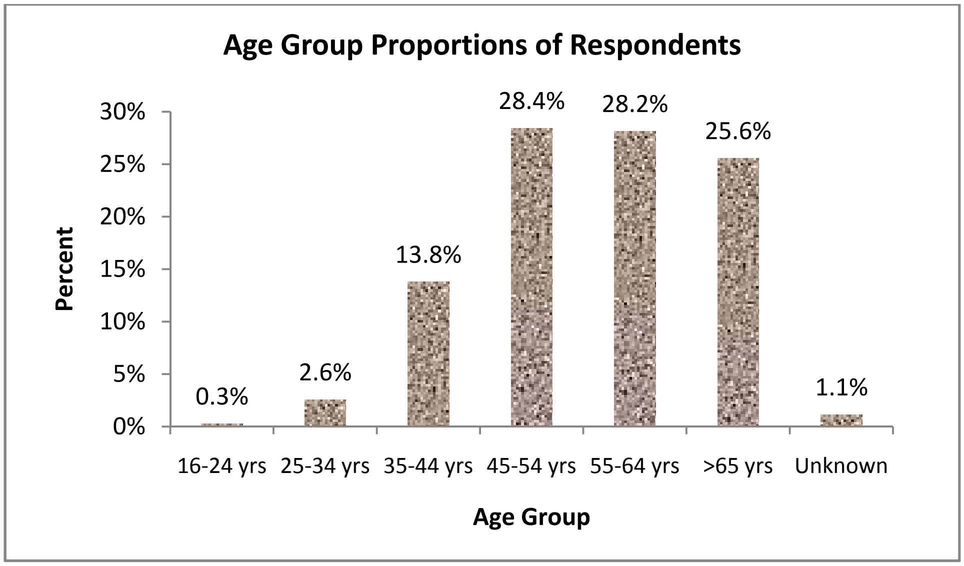


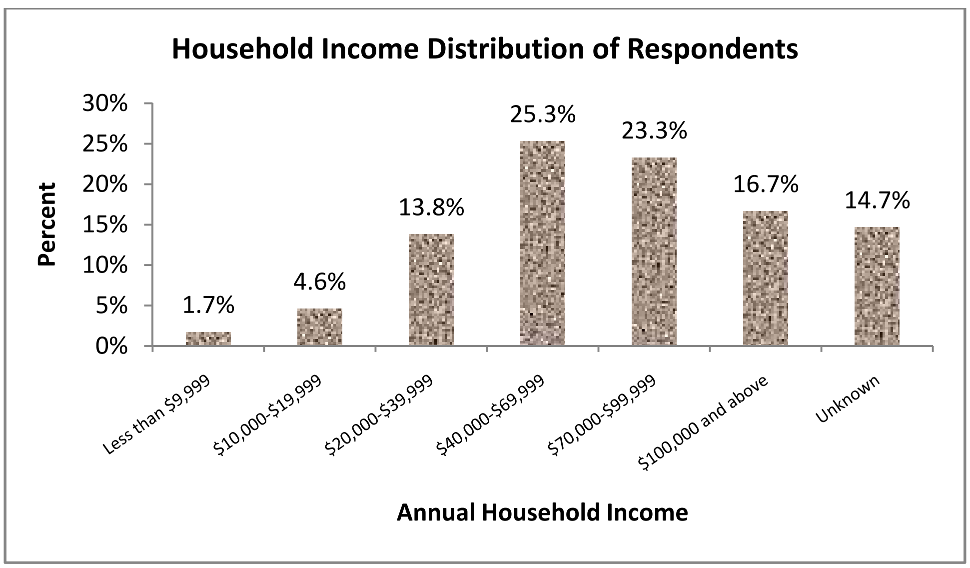
Figure 6.13 shows the distribution of age among the respondents. About 28% of the respondents were in the 45-54 and 55-64 years age groups, respectively. 25.6% were residents older than 65 years. Young citizens under 35 years accounted for 3% of the total.

Figure 6.13 Age Distribution of Survey Respondents



The annual household income of the respondents is categorized into six categories and the distributions are plotted in Figure 6.14. The range of $40,000-$69,999 accounts for the largest percentage of 25.3%, followed by $70,000-$99,999 and above $100,000.

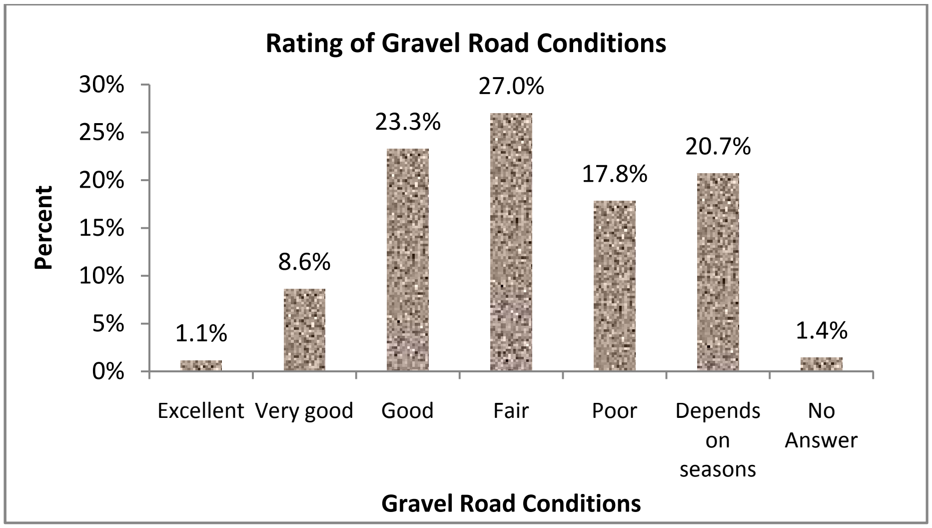
Figure 6.14 Annual Household Income Distribution of Survey Respondents



More than 95% of the respondents said they had been living in Kansas for more than 10 years. About 97% of the respondents have been driving for more than 20 years, and the other 3% have been driving for 10-20 years. Figure 6.15 shows the overall rating of gravel road conditions by the respondents based on their perspectives. 27% rated “Fair”, 23.3% rated “Good” and

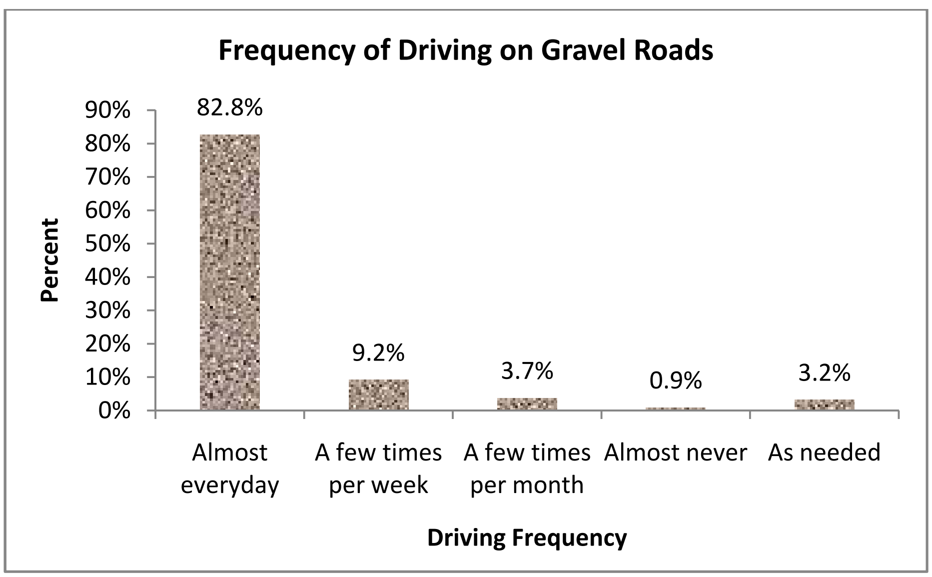
17.8% rated "Poor" to the conditions of gravel roads they are aware of. 20.7% indicated that the rating depends on seasons. Less than 10% said gravel roads are in excellent or very good conditions.

Figure 6.15 Overall Rating of Gravel Road Conditions by the Respondents



As shown from Figure 6.16, 82.8% of the respondents drive on gravel roads almost every day, 9.2% drive a few times per week on gravel roads, and about 8% drive gravel roads at very low frequencies or just as needed.

Figure 6.16 Respondents Distribution Based on Driving Frequency on Gravel Roads

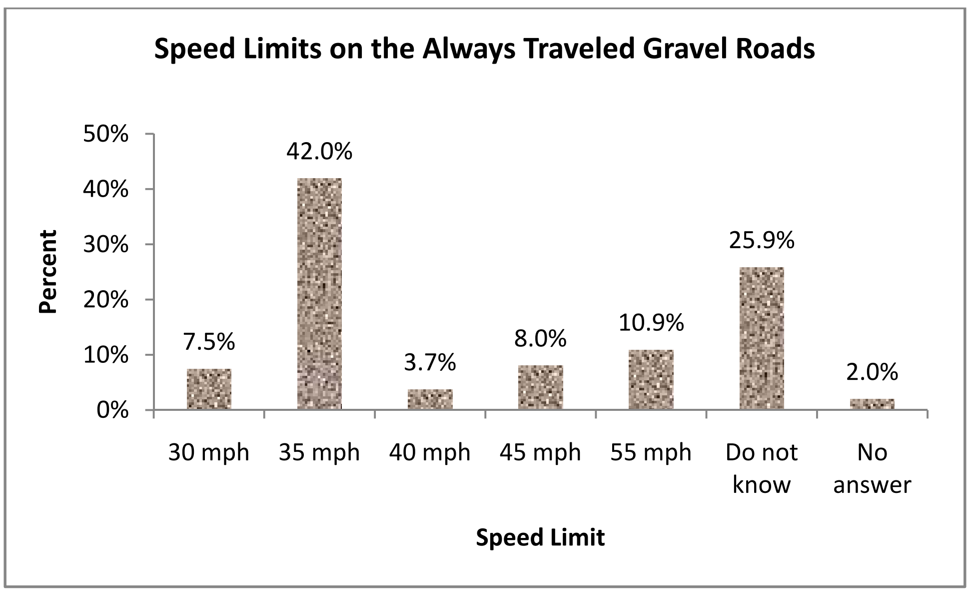


6.2.2 Concerns about Speed Limits on Gravel Roads

This subsection summarizes answers to the speed limit related questions (Question 5 through Question 15) in the survey.

Figure 6.17 shows the awareness of respondents of the speed limits on the gravel roads that they always drive. 25.9% of the respondents directly said they do not know the speed limit. About 72% of the total made their choices, as shown in the bar chart, 42% specified 35 mph, and 10.9% specified 55 mph. However, it is noticed that some respondents do not really know the correct speed limit since they made different choices from what most of their neighbors have done on the same road. It is estimated that more than 40% of the respondents do not know the actual speed limit on gravel roads that they always drive.

Figure 6.17 Distribution of Speed Limits on the Always Traveled Gravel Roads



As shown in Figure 6.18, of the total number of respondents, 68.1% answered YES and 31% answered NO when being asked about whether they know the speed limit on gravel roads is regulated by the law in Kansas.

Figure 6.18 Awareness of the Speed Law on Gravel Roads in Kansas

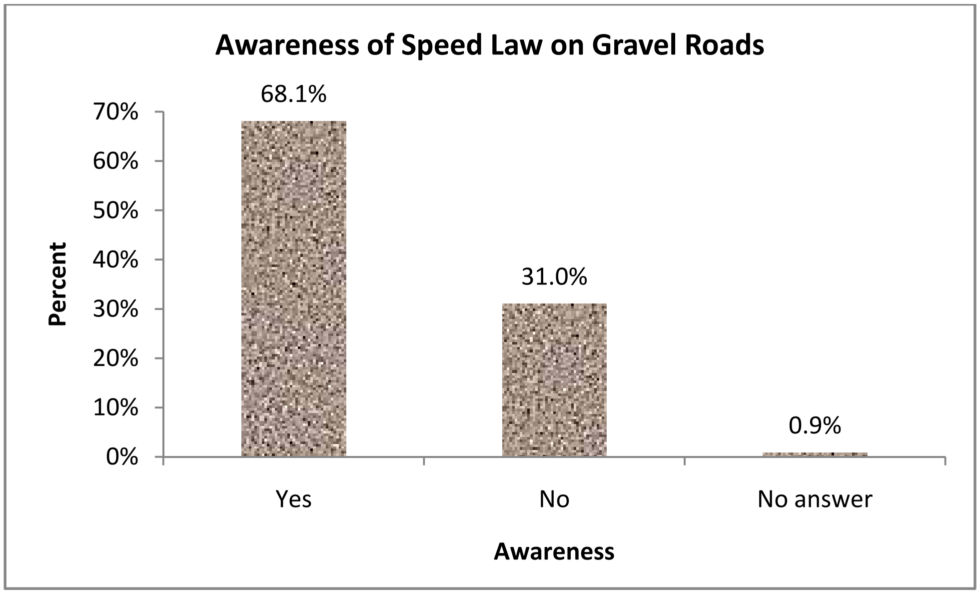
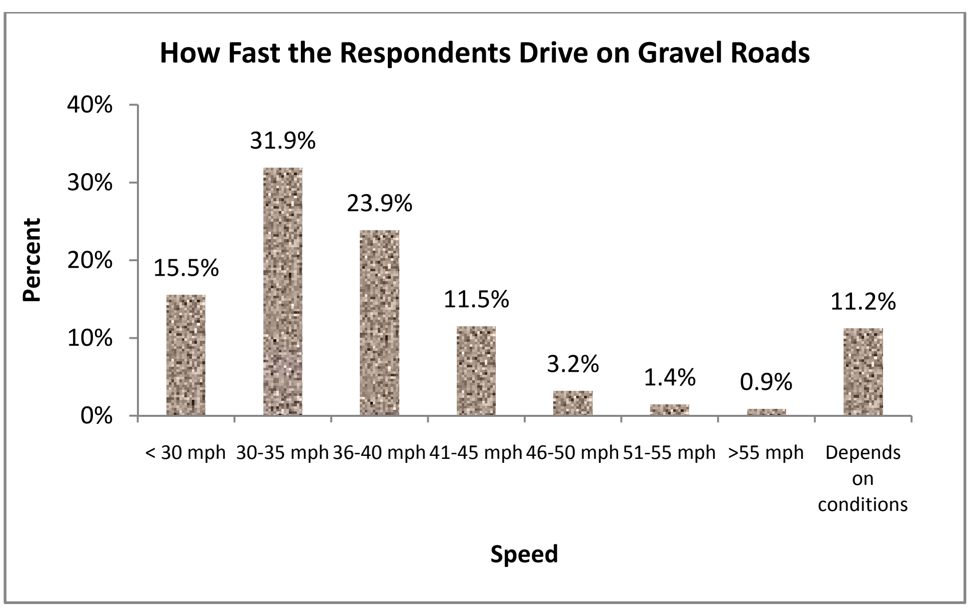


Figure 6.19 shows the percentage of the respondents based on their answers to how fast they usually drive on gravel roads. The largest proportion falls into the 30-35 mph speed category and then the 36-40 mph category. After combining some categories, it is found that 82.8% of the respondents said they usually drive on gravel roads at a speed below 45 mph. Only 5.5% answered that they usually drive faster than 45 mph. The remaining 11.2% said their speeds depend on existing conditions at the time of driving on gravel roads.

Figure 6.19 Common Speeds the Respondents Drive on Gravel Roads



When asked whether they normally follow the speed limits on gravel roads, 64.9% of the total respondents answered YES, 9.5% answered NO, and 22.4% depend on situations, as shown in Figure 6.20.

Figure 6.20 Consistence with Speed Limits on Gravel Roads

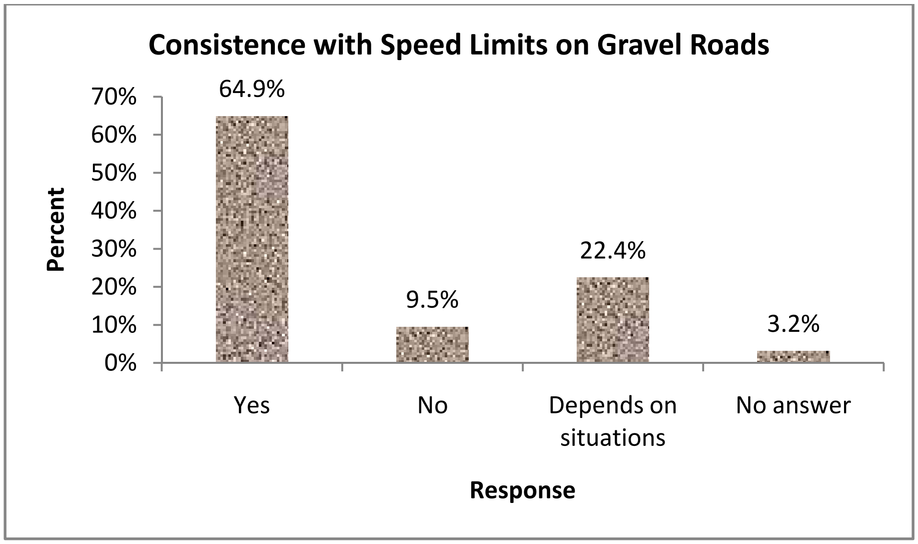
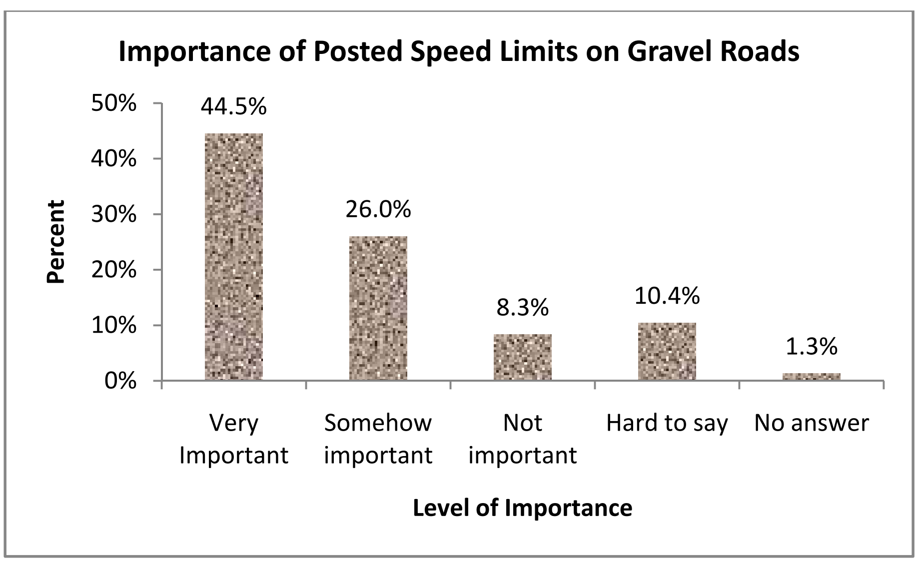


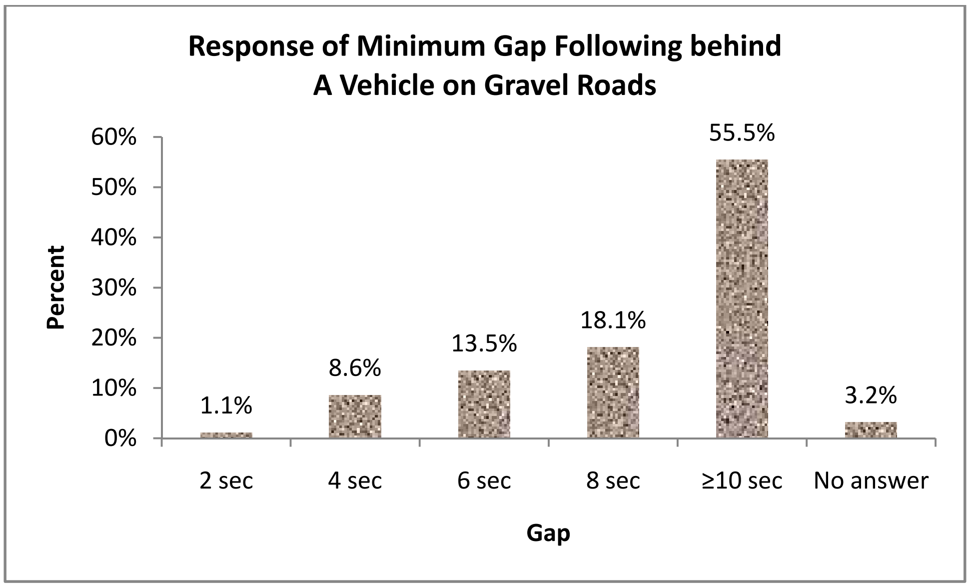
Figure 6.21 presents the responses to whether posted speed limit is important to control traffic on gravel roads. As shown in the figure, 44.5% of the respondents indicated that is is very important, 26% said it is somehow important, 8.3% did not think it is important and 10.4% said it is hard to say.

Figure 6.21 The Importance of Posted Speed Limits on Gravel Roads



Keeping an appropriate gap between two vehicles is important to prevent crashes. For the question of what the minimum gap to safely follow another vehicle on gravel roads is, over 55% of the respondents selected 10 seconds or larger as shown in Figure 6.22, 18% selected 8 sec, 13.5% selected 6 seconds, and less than 10% thought 2 or 4 seconds are enough. A Canada insurance corporation suggests drivers better stay at least 6 seconds behind other vehicles on gravel roads even if the visibility is good and the road is hard-packed (MPIC, 2007). It seems the majority of respondents have been aware of the potential hazards driving on gravel roads.

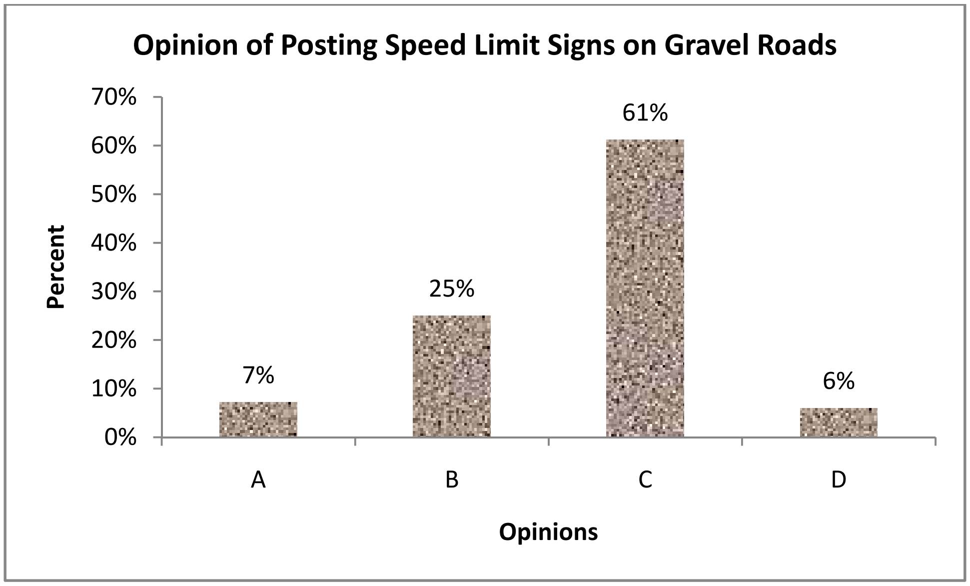
Figure 6.22 Response of Minimum Gap Following a Vehicle on Gravel Roads



13.2% of the respondents said they had been involved in an accident on gravel roads and 85.3% said NO. The operating speeds at the time of accident have a range from 0 to 55 mph while most occurred at speeds between 20 and 40 mph. There is only one respondent who answered he had been issued a ticket for speeding on a gravel roads.

Figure 6.23 presents the respondent distribution based on their opinions about posting speed limit signs on gravel roads. 61% of the total wanted to post all the gravel roads, 25% wanted to post only those sections where it has been requested by residents and have been approved by traffic engineers, 7% did not support posting any speed limit signs on gravel roads and 6% gave other answers. Those who do not want speed limit posted on gravel roads think that nobody would follow the signs and the money for posing speed limits should be used for road maintenance and improvement. Moreover, some respondents suggest posting only those special areas or sections, e.g. highly populated areas, major road (collector route), heavily-used roads or where speeding is a problem.

Figure 6.23 Opinions about Posting Speed Limit Signs on Gravel Roads



A = Do not post any speed limit signs on gravel roads

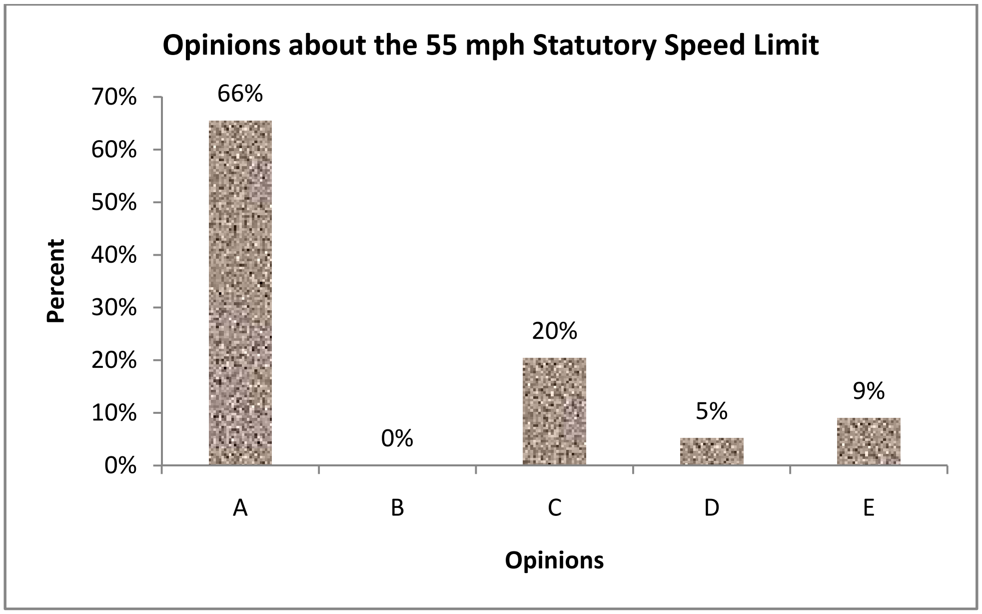
B = Only post where residents request and get approved by traffic engineers

C = Post on all the gravel roads

D = Other or no answers

Opinions regarding the current 55 mph statutory speed limit were shown in Figure 6.24. 66% of the respondents thought 55 mph is too high for gravel roads and needs to be reduced. 20% agreed with 55 mph and did not think it should be changed. 5% support not using any speed limits on gravel roads and let drivers judge speeds by themselves. Nobody thought it should be raised. A number of respondents gave comments saying 55 mph is apparently too high for gravel roads and should be lowered. However, some respondents wondered who would regulate these posted speed limit signs if they are posted on gravel roads.

Figure 6.24 Opinions about the 55 mph Statutory Speed Limit on Gravel Roads



A = Lower the 55 mph statutory speed limit.

B = Raise the 55 mph statutory speed limit.

C = Keep the 55 mph statutory speed limit unchanged.

D = Do not use any speed limit and let drivers judge the speeds by themselves.

E = Other or no answers

A total of twelve factors that possibly have impacts on traffic speed on gravel roads were ranks based on the level of importance which are classified into five levels, as shown in Table 6.2. The weight scores assigned to each level are: +3 for extremely important, +2 for very important, +1 for moderately important, 0 for somewhat important and -3 for not important. Based on the total scores, surface conditions is the most important factor that affects drivers judging their speeds on gravel roads, and it is followed by sight distance, weather, curves and dust in turn. Speed limit ranks the ninth position. Law enforcement and statutory regulations are considered as the two least important factors. Some other factors were mentioned as important elements when driving on gravel roads, such as traffic, trees, signage, wildlife and pedestrians.

Table 6.2 Rank of Influential Factors on Judging Speeds on Gravel Roads

Factors	Level of Importance										Total Score
	Extremely (+3)		Strongly (+2)		Moderately (+1)		Somewhat (0)		None (-3)		
Surface Conditions	235	67.5%	86	24.7%	24	6.9%	0	0.0%	2	0.6%	895
Sight Distance	84	24.1%	98	28.2%	110	31.6%	21	6.0%	21	6.0%	846
Weather	211	60.6%	88	25.3%	37	10.6%	4	1.1%	3	0.9%	843
Curves	160	46.0%	113	32.5%	67	19.3%	4	1.1%	2	0.6%	837
Dust	201	57.8%	105	30.2%	36	10.3%	1	0.3%	1	0.3%	824
Familiarity With Road	106	30.5%	105	30.2%	96	27.6%	17	4.9%	17	4.9%	782
Road Width	211	60.6%	90	25.9%	39	11.2%	2	0.6%	3	0.9%	767
Time	166	47.7%	118	33.9%	57	16.4%	3	0.9%	3	0.9%	709
Speed Limit	148	42.5%	110	31.6%	69	19.8%	10	2.9%	8	2.3%	573
Comfort	216	62.1%	79	22.7%	33	9.5%	13	3.7%	5	1.4%	572
Statutory Regulations	101	29.0%	106	30.5%	90	25.9%	29	8.3%	11	3.2%	495
Law Enforcement	99	28.4%	64	18.4%	94	27.0%	45	12.9%	36	10.3%	411

Altogether 176 respondents, 50.6% of total, provided their comments with respect to the issues on gravel roads. The typical comments are as follows:

- Dust is a tremendous problem for both drivers and residents who live on gravel roads. Huge amount of dust stirred up by traffic both pollute the environment and cause safety problems. Therefore, it is expected that traffic on gravel roads will slow down to reduce the amount of dust.
- Some people drive too fast on gravel roads, causing big dangers to those who live along gravel roads. Measures need to taken to slow down the traffic.

- Law enforcements are strongly needed to patrol the roads that have been posted. It is strongly believed that nobody would abide posted speed limit signs if no police officers are patrolling on the roads.
- Gravel roads should be properly and routinely graded.

6.2.3 Comparisons between Johnson County and Other County Respondents

In this subsection, comparisons were made between the input of two respondent groups, Johnson County respondents and the respondents from the other six counties on several related questions.

How the respondents considered the importance of speed limits on gravel roads is compared as shown in Figure 6.25. Compared to the other six counties, about 5% more of the respondents in Johnson County said speed limits are very important, and similar percentages accounted for other categories.

Figure 6.25 Importance of Posted Speed Limits on Gravel Roads

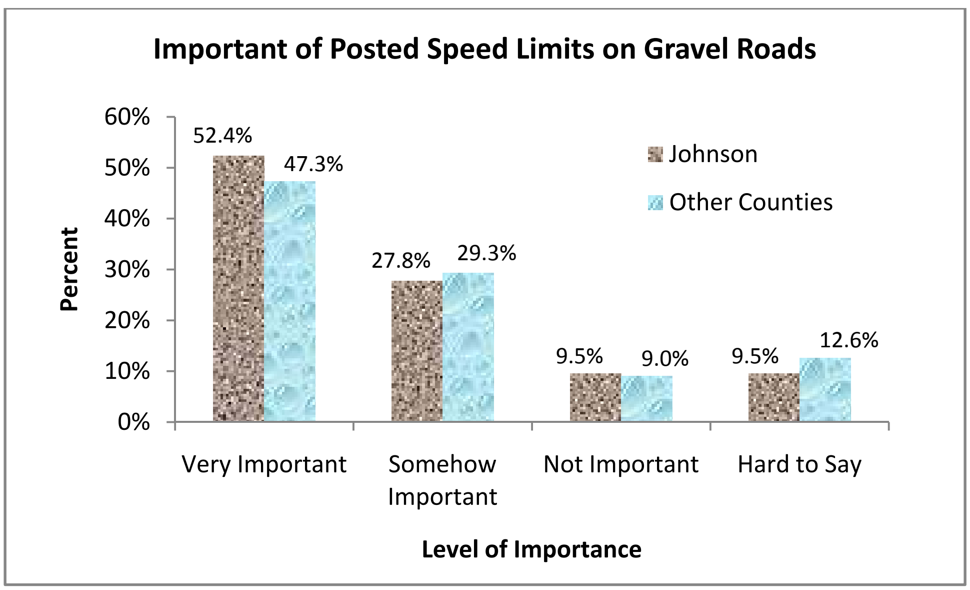
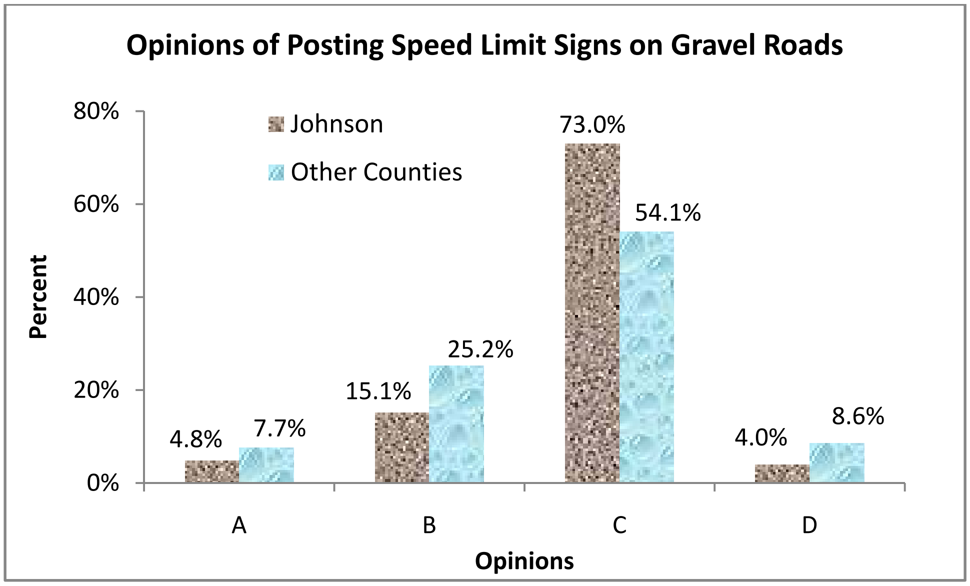


Figure 6.26 shows the comparison of opinions concerning posting speed limit sign on gravel roads. There was obviously a larger percent of respondents in Johnson County who support posting all the gravel roads, which is about 19% more than the percentage in the other six counties. Correspondingly, Johnson County had relatively smaller percent of respondents

who do not think gravel road should be posted or support to post part of gravel roads where speed limit signs are requested and approved.

Figure 6.26 Importance of Posted Speed Limits on Gravel Roads



A = Do not post any speed limit signs on gravel roads.

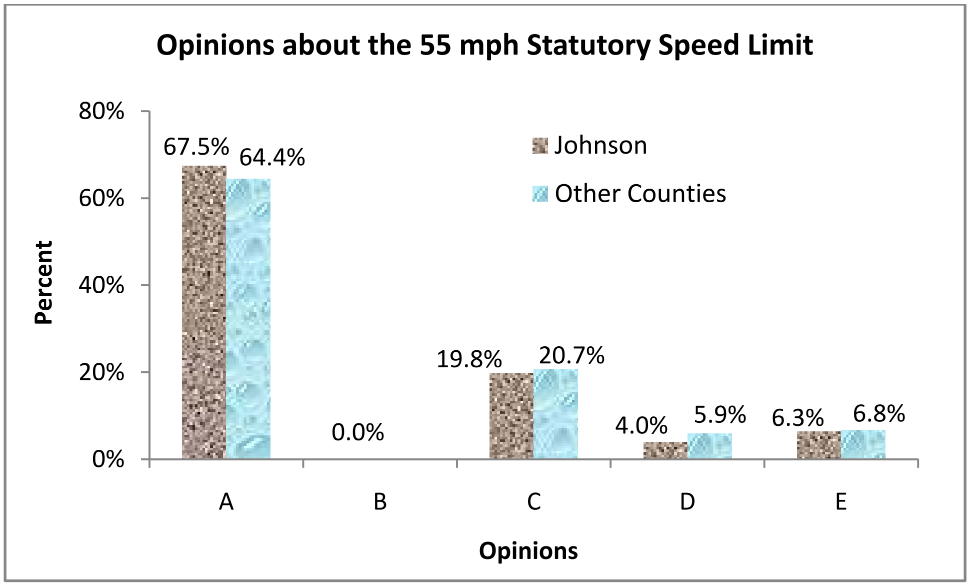
B = Only post where residents request and get approved by traffic engineers.

C = Post on all the gravel roads.

D = Other or no answers.

As shown in Figure 6.27, the opinions regarding the 55 mph statutory speed limit on gravel roads are also compared between the two groups. Johnson County had slightly higher percent of respondents in favor of lower regulatory speed limit than 55 mph for grave roads, compared to the other six counties. About 2% more of the respondents in the other six counties preferred not to set any speed limit on gravel roads. The percentages who do not want 55 mph to be changed in both groups are quite similar with only 0.9% difference.

Figure 6.27 Comparison of Opinions Regarding 55 mph Statutory Speed Limit



A = Lower the 55 mph statutory speed limit.

B = Raise the 55 mph statutory speed limit.

C = Keep the 55 mph statutory speed limit unchanged.

D = Do not use any speed limit and let drivers judge the speeds by themselves.

E = Other or no answers.

6.3 Summary of Surveys

The two sets of survey provided important perspectives from the viewpoints of both traffic professionals and road users. In general, it is interesting to note that the characteristics of gravel roads in these counties are so much diversified in many features like surface material, maintenance period and availability of funds. Speed limits are also adopted in various ways between different counties. For example, some counties have set all their gravel roads based on speed zoning while the others did not, or some posted certain sections on gravel roads like curves or bridges while some others did not.

There are clearly different opinions regarding whether or not all the gravel roads should be posed. Based on the traffic professional survey, it revealed that 75% of the counties are in favor of keeping on regulating gravel roads with a blanket speed limit and 66% have a desire that the blanket speed limit is posted on all the gravel roads. The reason behind this perspective can be described in a way as some respondents commented, “Speed limits on gravel roads are actually an enforcement issue, since establishing speed limits creates a responsibility to enforce the speed limit. Posted speed limits are not obeyed unless tickets are written. So if we will not patrol our gravel roads, why should we post the speed limits?" A summary of typical comments from county engineers is provided in Appendix C of this report.

This concern is also supported by the road user survey. Though the road user survey shows that most rural residents, especially who live along gravel roads, would like to see their gravel roads posted with lower speed limits, they have the same perspective as the traffic professionals that changing or posting a speed limit is not effective in controlling traffic if there is no law enforcement.

It was suggested by a number of traffic professionals and residents that speed signs be posted only at those locations of gravel roads where signage is really needed, such as highly populated areas, heavily-used roads, curves, hills or where speeding is a problem. Excessive posting of speed signs cannot bring real benefits to traffic safety without following-up enforcements but will possibly reduce the public respect to these speed signs. Instead, advisory speed plates and warning signs are suggested by some counties to be posted as needed to warn drivers to notice upcoming difficulties and hazards.

A group of influential factors that might affect establishing speed limits on gravel roads have been presented in Table 6.1. It implies that the critical factors to be considered while establishing speed limits on gravel roads are much different than those on paved roads. Surface condition, sight distance and road damage by heavy vehicles should be considered prior to 85th-percentile speed, roadside development and traffic volume, which are always critical factors for paved roads.

CHAPTER 7 - Summary, Conclusions and Recommendations

7.1 Summary

The procedure of establishing speed limits is a complicated progress and need to consider numerous factors from technical viewpoints to political viewpoints. As per the literature review, there is no specific guideline on the applicability of speed limits on gravel roads though some states are trying on it.

This research performed speed data collections on a number of field sites and then conducted statistical analysis based on the data. Analysis using t-test found that the mean speed of traffic on Johnson County gravel roads was not significantly different than that in other counties but was found to be higher than that in Miami County alone. Therefore, the application of 35 mph speed limit in Johnson County has not actually affected the traffic speeds. Two linear models based on the speed data were developed and indicated that both the 85th-percentile speed and mean speed are not associated with speed limit but are related to road width, surface classification and percentage of large vehicles.

The chi-square test analyzed the crash data in three stages and indicated that the 35 mph speed limit in Johnson County did not result in significant change in the crash distribution from its adjoining counties. The test for the statewide crash data implied that 55 mph gravel roads tends to have bigger proportion of severe crashes than lower speed posted grave roads. This finding is reasonable since those sections with lower speed posted are usually possibly dangerous or difficult for traffic to go through and hence cause drivers to pay more attention with results as lower speeds and reduced crash severity. However, this logistic does not apply to the 35 mph roads in Johnson County since the traffic do not actually reduce their speeds as testified in the speed study.

Both the speed and crash data analysis indicates that a posted lower speed limit on gravel roads do not have benefits in reducing traffic speeds and reduce crash severity as expected. In addition, it was found that surface classification is tightly related to traffic speeds. Usually, the more hard-packed the surface, the higher the traffic speeds. As per the speed model, sand-surfaced roads are very likely to have a 10 mph higher 85th-percentile speed than gravel-surfaced roads, and gravel roads with low-depth surfaces are likely to have a 3 mph higher 85th-percentile speed than roads with thick-depth surfaces.

The questionnaire surveys indicated that most of Kansas counties and rural residents, especially who live along grave roads, are very concerned about speed limit related issues on gravel roads. However, a large proportion of the residents are not aware of the speed limits that are applied to gravel roads they always drive on. It was also found that a number of gravel road users tend to judge their speed based on a variety of conditions, including surface, sight distance, weather and so on, instead of just complying with speed limits.

75% of the traffic professional respondents preferred blanket speed limit to speed zones for grave roads. Of the blanket speed limit favorers, 37% would like a smaller speed limit value, 8.8% thought 55 mph is correct, 5.3% preferred a higher number, and 49% did not show preferences on where it should be. 65.8% of the respondents did not think the blanket speed limit signs should be posted on gravel roads with considerations from three main aspects:

1. Posted speed limit signs do not apply to the changeful conditions of gravel roads, as weather and other factors tend to affect the road conditions significantly.
2. There is no enough or extra law enforcement to patrol the speed limits on gravel roads.
3. It costs too much expenditure to post speed limit sign on all the gravel roads, which is unaffordable for some counties.

The surveys found that a number of traffic professionals and most of road users are concerned about the actual effectiveness of posting speed limits on gravel roads. They believe that if there is no enforcement patrolling gravel roads, nobody will abide and show respect to the posted speed signs. It was suggested that advisory speed plates be used instead of speed limit signs on where as needed to direct drivers on gravel roads.

7.2 Conclusions and Recommendations

Based on the findings in this study and the actual design speed of gravel roads, the currently used 55 mph statutory speed limit is appropriate for current conditions of most of the gravel roads and widely accepted by the majority of county engineers in Kansas. The already reduced and posted speed limit signs on gravel roads in Johnson County were found to be of very limited use in controlling vehicle speeds and promoting traffic safety, therefore, are not suggested as speed limit criteria for other counties which are not using reduced speed limits on gravel roads.

Speed zones are suggested to be established on potentially hazardous locations on gravel roads, since this study finds that low traffic speed can dramatically reduce the probability of suffering an injury crash or at least reduce the severity of a crash that is going to happen on gravel roads. Since pedestrian involvement was revealed to be an important factor to cause injury or possible injury crashes, gravel roads in areas with a certain density of population can be considered to set speed limit signs to abatement the high economic costs caused due to injuries in motor vehicle crashes. Appropriate law enforcement is also suggested for gravel roads regulated by speed zones to make posted speed limit signs go into effect.

The 85th-percentile speed model developed in this study can be applied when establishing speed zones on gravel roads, especially for those sections where traffic volume is too low to be studied in an easy way. Road width and surface classification can be easily obtained from field study, and percentage of heavy vehicles could be estimated based on observation or pick up a value from a suggested range from 10% to 30% based on field studies in this research. In addition, surface condition, sight distance, and accident history also need to be considered in engineering investigations as these factors were ranked by county engineers to be very important on establishing speed limits on gravel roads.

Traffic professionals need to be cautious when establishing speed limits on gravel roads, since field studies observed that the majority of motorists on gravel roads drive in an approximately homogeneous manner without many driving too fast or too slow. An inadequately established speed limit, which aims to regulate a small portion of motorists who drive too fast, might disturb a number of well-behaving motorists who drive decently on gravel roads.

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Appendix A - Traffic Professional Survey Form

County Gravel Roads Survey on Speed Limits

COUNTY _____ NAME _____ TITLE _____

Please mark or fill the appropriate blank. Some questions are multiple-choice.

1) There are about _____ miles of gravel roads in this county, of which _____ miles are county roads and _____ miles are township roads.
   What is the approximate percentage of gravel roads at any given time that belong to each of the following categories in your county?
   i) Very few ruts, corrugations and potholes _____%
   ii) Moderate numbers of ruts, corrugation and potholes _____%
   iii) Plenty of ruts, corrugation and potholes _____%
   Total 100%

2) How frequently are the gravel roads maintained in your county?
   ☐ Less than 2 months ☐ 2 – 4 months ☐ 5 – 8 months
   ☐ More than 8 months ☐ Other (specify) _____

3) How much funds are annually available for gravel roads maintenance in your county?
   ☐ Less than $100,000 ☐ $100,000 - $300,000 ☐ $300,000 - $500,000
   ☐ $500,000 - $1,000,000 ☐ $1,000,000 - $3,000,000 ☐ More than $3,000,000

4) What types of gravel are usually used on gravel roads in your county?
   ☐ Crushed gravel ☐ Washed gravel ☐ Pit-run gravel ☐ Screened gravel
   ☐ Aggregate mix of gravel, sand and fines ☐ Other (specify) _____

5) From where do you get the gravel used for gravel roads maintenance?
   ☐ Local area ☐ Neighboring counties ☐ Far away counties ☐ Other (specify) _____

6) Are there any speed limit signs on special sections of gravel roads (such as curves, bridges, etc.)?
   ☐ Yes ☐ No

7) Are there any speed limit signs posted on general sections of gravel roads in your county?

☐ Yes ☐ No

If you answered “Yes”, please give the approximate road miles posted with the following speed limits.

☐ ≤ 25 _____miles ☐ 30 _____miles ☐ 35 _____miles ☐ 40 _____miles

☐ 45 _____miles ☐ 50 _____miles ☐ 55 _____miles ☐ > 55 _____miles

8) What criteria do you currently use in setting speed limits on gravel roads?

☐ Engineering study ☐ Statutory regulations/Blanket speed limit

☐ Professional judgment ☐ Panel discussion ☐ Public hearing

☐ Public survey ☐ Other (specify) _____

9) How are these speed limits adopted in your county?

☐ Applied to all the gravel roads ☐ In special speed zones

☐ Other (specify) _____

10) Have you or your agency ever received any complaints from the public related to gravel roads?

☐ Yes ☐ No

If yes, then what kinds of complaints have you or your agency received?

☐ Poor road conditions ☐ Narrow width ☐ Vehicle speeding ☐ Dust pollution ☐ Noise

☐ Safety ☐ High speeds ☐ Low speeds ☐ Other (specify) _____

11) What is your opinion on establishing speed limits on gravel roads? (Check all that apply)

☐ Should use blanket speed limit on gravel roads and the signs need to be posted.

☐ Should use blanket speed limit on gravel roads and there is no need to post speed limit signs.

☐ Prefer speed zones on some gravel roads because they work better than blanket speed limits.

☐ Only some gravel roads need to have speed limits and the rest do not need it.

☐ A blanket speed limit for gravel roads does not contribute to traffic safety.

☐ I prefer a higher speed limit than 55 mph on gravel roads.

☐ I prefer a lower speed limit than 55 mph on gravel roads.

☐ Other (specify) _____

12) How would you rank the importance of the following factors in establishing speed limits on gravel roads?

Factors	Importance			
	High	Moderate	Low	None
Surface Condition	☐	☐	☐	☐
85th Percentile Speed	☐	☐	☐	☐
Curvature	☐	☐	☐	☐
Road Width	☐	☐	☐	☐
Road Length	☐	☐	☐	☐
Sight Distance	☐	☐	☐	☐
Traffic Volume	☐	☐	☐	☐
Roadside Development	☐	☐	☐	☐
Public Attitude towards Speed Regulation	☐	☐	☐	☐
Accident History	☐	☐	☐	☐
Statutory Regulations	☐	☐	☐	☐
Maintenance Period	☐	☐	☐	☐
Road damage by heavy vehicles	☐	☐	☐	☐

13) Please comment on the acceptability of the criteria currently used in setting speed limits on gravel roads in your county.

Appendix B - Gravel Roads User Survey

We are conducting a survey to make travel on gravel roads better. You are invited to answer the following questions. The information collected is used for research purposes only. Please check the appropriate answer or fill in the blank. Thank you for your assistance.

1. How long have you lived in Kansas?
O Less than 1 year O 1 - 2 years O 2 - 5 years
O 5 - 10 years O More than 10 years

2. How long have you been driving?
O Less than 1 year O 1 - 5 years O 5 - 10 years
O 10 - 20 years O More than 20 years O Do not drive

3. How would you rate the conditions of gravel roads in Kansas?
O Excellent O Very good O Good
O Fair O Poor O Depends on the season

4. How often do you usually drive on gravel roads?
O Almost everyday O A few times per week O A few times per month O Almost never O As needed

5. What is the speed limit on the gravel roads you usually drive on?
O 30 mph O 35 mph O 40 mph O 45 mph
O 50 mph O 55 mph O 60 mph O Do not know

6. Do you know that the current speed limit on gravel roads is regulated by the law?
O Yes O No
If YES, please specify the value from the following numbers.
O 25 mph O 30 mph O 35 mph O 40 mph
O 45 mph O 50 mph O 55 mph O 60 mph

7. Roughly speaking, how fast do you usually drive on gravel roads?
O < 30 mph O 30-35 mph O 36-40 mph O 41-45 mph
O 46-50 mph O 51-55 mph O > 55 mph O Depends on conditions

8. Do you normally follow the speed limits on gravel roads?
O Yes O No O Depends on situations

9. Please rate the following factors that are likely to affect your speed on gravel roads.

	Not Important 1	2	Moderately Important 3	4	Extremely Important 5
Surface Conditions	☐	☐	☐	☐	☐
Statutory Regulations	☐	☐	☐	☐	☐
Curves	☐	☐	☐	☐	☐
Road Width	☐	☐	☐	☐	☐
Sight Distance	☐	☐	☐	☐	☐
Speed Limit	☐	☐	☐	☐	☐
Weather	☐	☐	☐	☐	☐
Familiarity with Road	☐	☐	☐	☐	☐
Time (i.e. day or night)	☐	☐	☐	☐	☐
Dust	☐	☐	☐	☐	☐
Comfort	☐	☐	☐	☐	☐
Law Enforcement	☐	☐	☐	☐	☐
Other (i.e.______)	☐	☐	☐	☐	☐

10. What do you think about the importance of posted speed limits on gravel roads?
O Very important O Somehow important
O Not important O Hard to say

11. Which is the minimum gap to safely follow behind another vehicle on gravel roads?
O 2 sec O 4 sec O 6 sec
O 8 sec O 10 sec or larger

12. Have you ever been involved in a crash on gravel roads?
O Yes O No
If YES, how many times? ______
How fast did you drive at the time of the crash? __________

13. Have you ever been issued a ticket for speeding on a gravel road?
O Yes O No

14. Please comment on the ***Speed Limit Signs*** on gravel roads.
O Do not post any speed limit signs on gravel roads.
O Only post where residents request and get approved by engineers.
O Post on all the gravel roads.
O Other (specify)
____.

15. What do you think about the ***55 mph regulatory speed limit*** for gravel roads?
O Lower the 55 mph regulatory speed limit.
O Raise the 55 mph regulatory speed limit.
O Keep the 55 mph regulatory speed limit unchanged.
O Do not use any speed limit and let drivers judge the speeds by themselves.
O Other (specify) ____.

16. Your age group?
O 16 - 24 yrs O 25 - 34 yrs O 35 - 44 yrs
O 45 - 54 yrs O 55 - 64 yrs O Older than 65 yrs

17. Sex?
O Male O Female

18. Your annual household income?
O Less than $9,999 O $10,000 - $ 19,999
O $20,000 - $39,999 O $40,000 - $ 69,999
O $70,000 - $99,999 O $100,000 and above

19. If you have any comments regarding speed limit related issues on gravel roads, please write it down on the blank lines below.

____
____
____
____
____
____
____.

-- End --

Thank you very much for completing this questionnaire. Your input will be greatly helpful to our research. Please place the completed survey form in the enclosed envelope and send it back to us. We appreciate you taking time to complete the survey. Thank you!

Appendix C - Typical Comments of County Engineers

	Comments
1	"By using statutory regulations for speed limits on gravel roads, the general public do not know the rule or choose not to pay attention to it. However, posting speed limit signs is too expensive in a county our size"
2	"Posting of specific speed limits has marginal impact. Sheriff does not patrol road due to other duties"
3	"Do not set limits"
4	"Due to increase of agriculture and oil & coal production, county roads are receiving heavy loads. We use an annual road reconstruction plan to improve a determined number of miles each year. This will improve the roadways because of the increase demand"
5	"Establishing speed limits creates a responsibility to enforce the speed limits. This county would probably need to add 7-8 officers with vehicles to enforce a blanket speed limit on gravel roads"
6	"Gravel roads are generally low-volume rural roads with little or no enforcement. I don't believe speed limits will work under those conditions"
7	"I feel statutory speed limits are fine the way they are. Weather doesn't affect asphalt roads as it affects gravel roads. There is no way of controlling the condition of gravel roads from week to week"
8	"I prefer not to set speed limit on county gravel roads in my county"
9	"The main thing in our area is the money to maintain county roads. I still believe it takes as much to maintain a county road properly as it does a paved road"
10	"Not an issue of any regular frequency"
11	"Not enough enforcement"
12	"Since speed limits should be based on engineering judgment, there are adequate criteria available until specific studies are undertaken"
13	"Speed limits are not posted in our county. They are not set on gravel roads"
14	"Speed limits less than 55 mph are requested by the public. The County Commissioners then adopt a resolution accordingly"
15	"Speed limits on gravel roads are an enforcement issue. If they aren't patrolled, then why post speed limit"

16	"Speed limits on gravel roads in our county are currently regulated by KSA 8-1557 which dictates that a person should not drive faster than a speed in which they are able to control the vehicle in a safe manner. This basic principle is what regulates the speeds on the majority of the gravel roads. Due to a number of variables, such as site distance over and around curves, width of roadway, the depth of gravel and rock that would cause less traction and control, as a role in determining the safe speed that one can travel on a county road and still maintain a total control of the vehicle and operate the same in a safe manner. Certain locations do have speed limits imposed are less than 55 mph for safety purpose and these normally are a result of some factor that causes a diminished amount of control or ability to operate safely"
17	"There are not enough sheriffs deputies/state troopers to enforce. Posted speed limits are not obeyed unless tickets are written. The old terms "common sense" and "reasonable and proper" apparently no longer apply (to more than just speed)"
18	"There will not be enforcement. Lower speed limits may increase speed differential, resulting in lower safety"
19	"This is difficult to do because of changing conditions"
20	"We did an engineering study to determine the speed limits on our gravel roads"
21	"We do not have posted SL on our gravel roads and feel that 45 mph is a safe speed on gravel roads. We have a small Sheriff Department. It would be paid for them to enforce a speed limit on our gravel roads"
22	"We typically only study road sections upon receiving a complaint or concern from citizens, townships, etc. We have not been posting improved sections of township gravel roads (e.g. improved as part of culvert replacement project), but were just notified by county counselor we should be. I'd like to see blanket speed limit on gravel roads (say, 40mph), then post portions that should be traveled at less than the blanket speed limit"
23	"We use a blanket speed limit except at curves and some bridges"
24	"Whenever you regulate traffic in any way, you will always have those in favor and those opposed. Where we do set speed limits, we base it mostly on safety issues"
25	"Currently the Board of Commissioners must pass a resolution to post a speed limit sign. We currently have no signs posted on gravel roads"
26	"Setting speed zones should remain an engineering process and not become a political process where blanket speed zones placed because of "issues" in one area cause drivers across the entire county to be restricted in their driving"