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Gravel Road Paving Guidelines

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The percentage of gravel roads in rural areas in Kansas is higher than most states. A wide variation of traffic volumes across different regions and variations of local conditions and scenarios present a great challenge for local agencies to determine the suitable roadway surface type for local rural roads, especially considering constraints on transportation budgets. The primary objective of this research was developing specific guidelines to identify the most suitable roadway surface (gravel vs. paved) for a particular roadway section with given conditions. Surveys were carried out to determine the importance of factors affecting the selection of a roadway surface type, which were later used for guideline development.

General guidelines were developed using the multi-criteria assessment method in order to fulfill the objectives in this study. The key factors in decision-making in regards to paving were identified as agency cost, safety, vehicle operating cost (VOC), traffic volume, purpose of road usage, and public preference. Multi-criteria assessment method involves calculating the weights for the factors important in decision-making, obtaining respective scaled values for each factor for paved and gravel surfaces, and eventually calculating the final score for paved and gravel surface type. Equations were formulated to carry out life-cycle cost (LCC) analysis along with the present worth evaluation, which provided flexibility to calculate agency cost by considering local conditions. VOC could be calculated for paved and gravel roads considering variations in the speeds of different classes of vehicles, gradient and horizontal curvature of the road, and the conversion factor for cost on paved surface versus gravel surface. Safety analysis was carried out for local rural roads in Kansas for 5 years, from 2010 to 2014, using the Kansas Department of Transportation's Kansas Crash Analysis and Reporting System (KCARS) database. After calculating the equivalent property damage only (EPDO) crash rates on paved and gravel roads in Kansas, results showed that paved surfaces were in general safer than gravel surfaces, which was taken into consideration while calculating the scaled values for safety. The final score is calculated by multiplying the weights of each factor and their respective scaled values. The roadway surface type with a higher score is the preferred alternative for a road section under consideration.

A computer-based Gravel Road Paving Guidelines Program was created as a user interface, using Visual Studio to carry out all complex calculations for determining LCC and VOC considering local variations. The program also helped determine final total scores for paved and gravel roads by considering scaled values of all important factors considered for conversion. Another approach using cost versus traffic volume showed that the break-even point for traffic volume decreased with an increased percentage of trucks and increased vehicle speeds. Developed guidelines help determine the best roadway surface type for any set of local conditions. The Gravel Road Paving Guidelines Program is available upon request to KDOT#Research.Library@ks.gov.

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Final Report

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PREFACE

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

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Abstract

The percentage of gravel roads in rural areas in Kansas is higher than most states. A wide variation of traffic volumes across different regions and variations of local conditions and scenarios present a great challenge for local agencies to determine the suitable roadway surface type for local rural roads, especially considering constraints on transportation budgets. The primary objective of this research was developing specific guidelines to identify the most suitable roadway surface (gravel vs. paved) for a particular roadway section with given conditions. Surveys were carried out to determine the importance of factors affecting the selection of a roadway surface type, which were later used for guideline development.

General guidelines were developed using the multi-criteria assessment method in order to fulfill the objectives in this study. The key factors in decision-making in regards to paving were identified as agency cost, safety, vehicle operating cost (VOC), traffic volume, purpose of road usage, and public preference. Multi-criteria assessment method involves calculating the weights for the factors important in decision-making, obtaining respective scaled values for each factor for paved and gravel surfaces, and eventually calculating the final score for paved and gravel surface type. Equations were formulated to carry out life-cycle cost (LCC) analysis along with the present worth evaluation, which provided flexibility to calculate agency cost by considering local conditions. VOC could be calculated for paved and gravel roads considering variations in the speeds of different classes of vehicles, gradient and horizontal curvature of the road, and the conversion factor for cost on paved surface versus gravel surface. Safety analysis was carried out for local rural roads in Kansas for 5 years, from 2010 to 2014, using the Kansas Department of Transportation's Kansas Crash Analysis and Reporting System (KCARS) database. After calculating the equivalent property damage only (EPDO) crash rates on paved and gravel roads in Kansas, results showed that paved surfaces were in general safer than gravel surfaces, which was taken into consideration while calculating the scaled values for safety. The final score is calculated by multiplying the weights of each factor and their respective scaled values. The roadway surface type with a higher score is the preferred alternative for a road section under consideration.

A computer-based Gravel Road Paving Guidelines Program was created as a user interface, using Visual Studio to carry out all complex calculations for determining LCC and VOC considering local variations. The program also helped determine final total scores for paved and gravel roads by considering scaled values of all important factors considered for conversion. Another approach using cost versus traffic volume showed that the break-even point for traffic volume decreased with an increased percentage of trucks and increased vehicle speeds. Developed guidelines help determine the best roadway surface type for any set of local conditions. The Gravel Road Paving Guidelines Program is available upon request to KDOT#Research.Library@ks.gov.

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Chapter 1: Introduction

1.1 Background

According to the Federal Highway Administration (FHWA), the United States has approximately 1.4 million miles of unpaved roads, totaling one-third of total roadway miles. Unpaved roads primarily include gravel roads and some dirt roads. Gravel roads account for a large number of rural roads in the United States, especially in Midwestern states such as Kansas. Kansas ranks fourth in the United States in terms of total mileage of roads, with approximately 140,687 miles, and ranks second in rural road mileage, with 127,048 miles. Kansas also ranks second in the United States for mileage of rural local roads, with 87,051 miles (FHWA, 2014). Therefore, Kansas, similar to other jurisdictions, will have to use limited transportation money wisely in order to properly maintain all roads. Kansas counties maintain 81,655 miles of rural local roads. Figure 1.1 shows the distribution of roadway surface types for all rural local roads maintained by Kansas counties (KDOT, 2013).

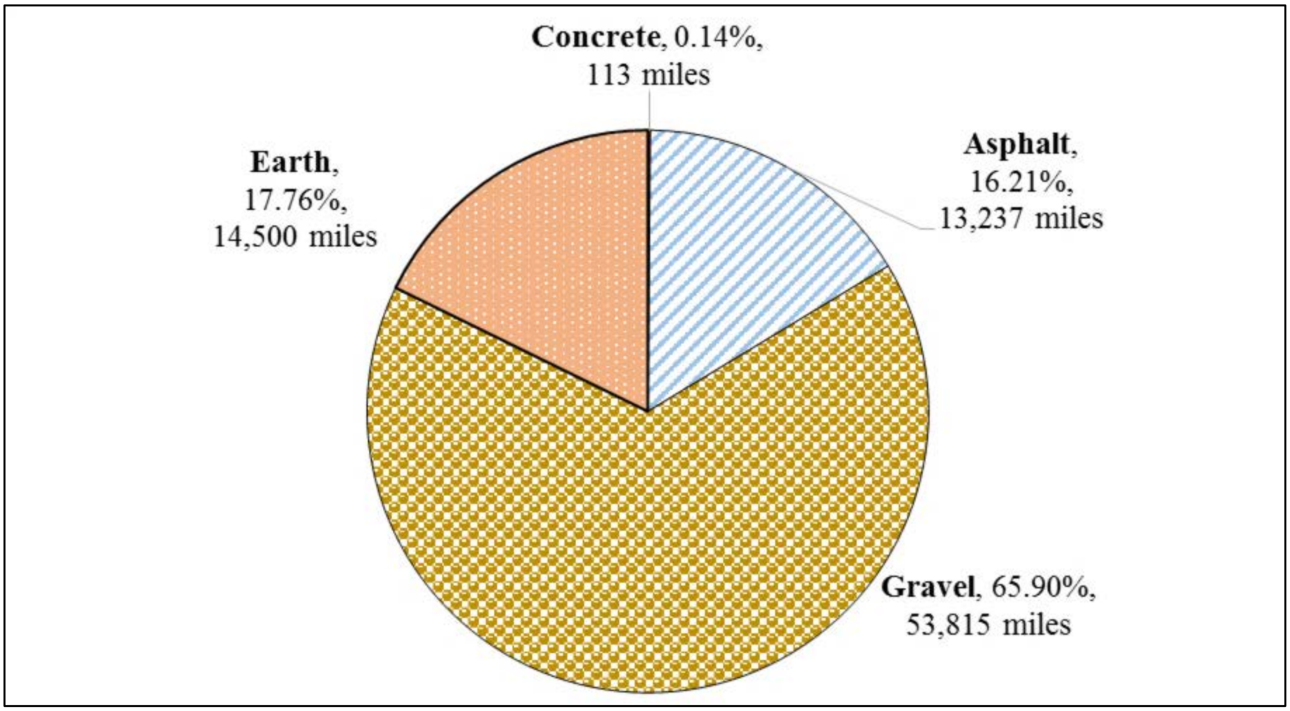


Figure 1.1: Distribution of Roads Maintained by All Kansas Counties Based on Roadway Surface Type (2013)

Gravel roads, which comprise almost 66% of total roads maintained by counties, have to be properly maintained, and in time it must to be determined whether to leave them as gravel roads or upgrade them to paved roads due to certain conditions. The extensive mileage of local rural roads and gravel roads in Kansas requires additional study of local rural roads to put the available resources to proper use.

1.2 Problem Statement

One of the major constraints for proper road maintenance in any state is the transportation budget. An increasing population and increasing number of motor vehicles on roadways require additional resources for maintaining roads. In addition, annual labor and material costs are also rising. However, transportation budgets do not increase at the same rate, resulting in a lack of resources for proper maintenance of roads. Local transportation agencies are trying to identify cost-effective ways to maintain roads under their jurisdictions based on their requirement.

A paved road with new asphalt overlay efficiently accommodates relatively high traffic volumes and requires minimum maintenance throughout the life of the road. However, maintenance of a worn-out paved road requires an expensive new asphalt overlay, at which point agencies might consider converting the paved road back to gravel. Again, gravel surface with high traffic volume demands frequent maintenance which results in higher maintenance cost. Therefore, determination of the preferred roadway surface (gravel or paved) is difficult, especially when considering cost-effective maintenance for the given traffic flow. Other factors, such as purpose of road usage, dust problems, and public preference help determine the preferred road surface type because each factor favors a particular surface type. For example, high initial conversion costs of a gravel road to a paved road favor a gravel-surfaced road, but when considering safety and vehicle operating cost (VOC), public preferences favor paved surfaces. Agencies are having difficulty in deciding which roadway surface should be utilized, considering minimum budget impact and maximum benefits to the public. Therefore, all factors must be assessed and guidelines must be developed to help agencies determine the most economical and acceptable roadway surface for given traffic volume and other conditions.

1.3 Objectives

The primary objective of this study was to develop standardized guidelines to identify the most suitable roadway surface for a particular roadway section with given conditions. Guidelines would help decision makers determine whether to convert a roadway surface from gravel to paved or vice versa or to maintain the road in its present state. Local governments can use the developed guidelines and determine the most suitable roadway surface types for rural roads in Kansas according to different local conditions. In addition to the direct impact of agency cost, factors such as average annual daily traffic (AADT), purpose of road usage, etc. must be taken into account before determining the road surface type. Results of this study will help in determining the most appropriate roadway surface for any given road considering local variation in maintenance practices, traffic volume, and safety. The secondary objective of this study was to provide a user-friendly computer-based program that county officials can use to work through calculations of the proposed methodology according to the guidelines while considering local variations. The user-friendly interface provides flexibility to the county officials to assess roadway sections with unique maintenance practices or AADT variations.

1.4 Outline of Report

This report consists of six chapters and five appendices. Chapter 1 presents a brief introduction and background of local rural roads in Kansas, the problem statement, and objectives of the research. Chapter 2 provides a literature review of maintenance activities on gravel roads and paved roads and safety issues on local rural roads. Chapter 3 describes methods of data collection and details of maintenance practices, as well as historical costs from six counties in Kansas. Chapter 4 describes the methodology used to develop the guidelines and the formulation of equations used for guideline development. Chapter 5 describes development of the guidelines and development of a user-friendly computer-based program to carry out calculations for variations. All proposed methodology used to develop the guidelines is also explained using a real-world example in Chapter 5. Chapter 6 provides a summary and the conclusions from this research and recommendations for further research. Appendix A includes a summary of road system types for county roads in Kansas. Appendix B contains the survey questionnaire used for the research, and Appendix C includes survey comments from county officials. Appendix D presents all relevant tables from the book *Economic Analysis for Highways* that were used to calculate the VOC (Winfrey, 1969). Appendix E includes the safety evaluation-related summary, tables, and calculations of crash details on local gravel and paved roads in Kansas. Appendix F includes the screenshots of the computer program developed for the research.

Chapter 2: Literature Review

This chapter presents an extensive literature review related to understanding maintenance procedures and safety-related issues for local low-volume rural roads. A number of relevant studies focused on maintenance activities on gravel and paved roads, costs associated with those activities, life-cycle cost (LCC) analysis for various pavement surface types, and safety-related discussions are provided.

2.1 Relevant Studies on Low-Volume Rural Roads

Most local roads in the United States are classified as low-volume roads (LVRs), meaning that they carry a traffic volume of 400 vehicles per day (vpd) or less (AASHTO, 2001). Although LVRs in the United States carry only 8% of total roadway travel, they constitute more than two-thirds of public highway mileage (FHWA, 2014). Due to the extensive mileage of LVRs and limited financial resources available to support that mileage, LVRs are historically designed to be operated at minimal cost. A considerable number of studies have been carried out to determine optimal maintenance practices for gravel roads in order to extend sustainability and cost efficiency.

The *Gravel Roads Maintenance and Design Manual* written in South Dakota identified detailed maintenance procedures for gravel roads (Skorseth & Selim, 2000). This manual described all maintenance activities on gravel roads, including details for effectively performing those activities using proper equipment. The manual also explained the design of proper crown for gravel surface roads in order to increase road durability using proper drainage. Similarly, another study detailed maintenance activities on paved roads. The handbook described distresses on paved roads and cost-effective maintenance treatments to enhance road performance (Johnson, 2000). The treatments discussed could be used for any paved road with any traffic volume.

In addition to identifying the most economical way to maintain a gravel roadway surface or a paved roadway surface, it is necessary to understand when to convert gravel surface to paved surface or vice versa. In Kansas, chip-sealed roads are classified in the category of paved roads. Local roads with low traffic volumes are generally gravel-surfaced; roads with high traffic volumes are typically chip sealed or paved. The following studies explain the increased maintenance costs related to increased traffic volume.

One study analyzed LVR surface types using a pavement management system created for the U.S. Forest Service's LVR network. Three pavement types were considered for the study: aggregate (gravel), surface treatment (chip sealed), and hot mix asphalt (HMA; paved). Total life-cycle costs for each roadway surface type were estimated based on various traffic mixes and traffic volumes. Results showed that gravel and chip-sealed roads became more expensive than HMA-surfaced roads as traffic increased due to increased maintenance and rehabilitation costs (Luhr & McCullough, 1983). A study conducted for the Minnesota Department of Transportation (MnDOT) examined when it was economically advantageous to upgrade and pave aggregate roads (Rukashaza-Mukome, Thorius, Jahren, Johnson, & White, 2003). The overall objective of the study was to identify the methods and costs of maintaining and upgrading an aggregate road. The researchers determined that maintenance costs (on a per mile basis) were higher on gravel roads than bituminous-surfaced roads within average daily traffic (ADT) ranges of 100 vpd; maintenance costs showed a considerable increase at ADT values greater than 200 vpd. Researchers concluded that ADT ranges from 100 to 200 vpd should initiate the idea for considering upgrading a gravel road.

Although no magical number for traffic volume differentiates roads with lower traffic and higher traffic rates, a few studies have shown that roads with traffic volume of 200 vpd or less should generally be gravel-surfaced, while roads with traffic volume more than 200 vpd should have paved surfaces (DiBiaso, 2002). However, this is not true for the entire scenario; although traffic volume is one significant factor for determining roadway surface type, it is not the only factor. ADT of 200 vpd is subjective and provided as a recommended threshold value for consideration of roadway surface type conversion. A few research studies have determined factors for consideration when converting from a gravel-surfaced road to a paved surface and vice versa. In addition to agency cost, traffic volume was a deciding factor for roadway surface type. Other factors include heavy vehicle traffic and type of required maintenance activities (Discussion on Paving Rural Gravel Roads, 2011). The study for MnDOT revealed that snow removal costs for paved surface roadways exceeded the costs on non-surfaced (earth or gravel) roadways by 20%, signifying the need to include snow removal costs when comparing maintenance costs of roadway surface types (Rukashaza-Mukome et al., 2003).

A study in Washington County, Oregon, used economical cost comparison methods to investigate approximately 80 LVRs upgraded from gravel to a hard surface. The county had 413 miles of local roads comprised of 39% paved surfaces and 61% gravel surfaces. Washington County's cost records over 20 years showed that the average cost to maintain 250 miles of gravel roads was $3,160 per mile per year. This paper also completed a specific study of 20 gravel roads. A correlation between traffic volume and maintenance cost was sought, and a graph with cost per mile per year versus traffic volume was plotted. Regression analysis of the data showed that grading and rocking costs could be estimated by the formula $C = 8.84V + \$2{,}164$, where C is the average maintenance cost per mile per year and V is the traffic volume or ADT. Upgrading a gravel road to a three-shot chip-sealed surface cost approximately $110,000 per mile. An additional single-shot chip seal was applied every 10 years, costing $37,000 per mile. Considering these costs, the break-even point for traffic volume of 145 vpd was obtained. Thus, the authors recommended that LVRs with ADT greater than 145 vpd should be chip sealed (Clemmons & Saager, 2011).

A study from North Dakota investigated strategies for maintaining gravel roads and selecting efficient and economic roadway surface types (Smadi, Hough, Schulz, & Birst, 1999). The authors noted that the decision for selecting a roadway surface type is not based solely on ADT, but that factors such as changes in the needs of rural road users, budget constraints, and a shortage of quality gravel also affect road-surfacing decisions. The primary focus of the research was to evaluate the most feasible time to pave gravel roads. The report recommended application of LCC analysis that considers conventional agency costs and user costs such as VOC. The approach included various steps. First, gravel roads that reached a threshold and required paving were identified. Second, data such as surface characteristics, traffic data, and annual maintenance costs were collected on roads and typical flexible pavement designs were developed to meet current and future ADT using appropriate design standards. Finally, LCC for the existing gravel surface and the designed paved surface were estimated over the analysis period, and the surface alternative with the lowest LCC was selected. The authors acknowledged that legal, political, and budgetary constraints must also play a role in the process and may actually control the final selection.

For a project in Minnesota (Jahren et al., 2005), researchers examined roadway surface construction costs and maintenance costs to determine possible threshold values to convert gravel-surfaced roads to paved-surfaced roads. This study analyzed county maintenance costs, maintenance practices, and traffic volume details for individual roads. This information helped determine an optimal time to achieve economically advantageous upgrading of a roadway surface depending on cumulative maintenance costs. Initial data collection for the project included 16 Minnesota counties, divided into four geographical regions around the state, with uniform and detailed information. It included information for the years 1997–2001 with maintenance cost per mile for bituminous (paved) roads and gravel roads, as well as traffic volume on the roads. One of the counties had historical data for many previous years on four roadway sections (two of each, paved and gravel). The historical data showed that cumulative maintenance costs per mile for high volume gravel roads (ADT = 130 vpd) were significantly higher than low-volume gravel roads (ADT = 60 vpd), low-volume paved roads (ADT = 225 vpd), and high-volume paved roads (ADT = 1,200 vpd). Out of the 16 counties, four counties with records of detailed traffic volumes and mileage of bituminous (paved) roads and gravel roads were further analyzed to develop a typical maintenance cost per mile for various roadway surface types. It showed that average maintenance costs for gravel roads were higher than for paved roads. Later, the roads were grouped by traffic volume, and the variation of maintenance cost per mile for paved roads and gravel roads with traffic volume was determined. Results showed that the maintenance cost per mile for gravel roads increased significantly compared to the paved roads when traffic volume exceeded 200 vpd. Thus, the study recommended a threshold value for traffic volume as 200 vpd. The researchers mentioned that a similar study could be adopted by other regions or similar cost information could be developed in order to obtain the threshold value.

This same study also discussed development of a method to estimate the cost of maintaining gravel roads when historical cost data is lacking or unreliable (Jahren et al., 2005). The cost of gravel roads was estimated by knowing or predicting the requirements of labor, equipment, and materials. Cost estimation was carried out for 1 mile of a standard gravel road section with 24-ft roadway top and 2-ft shoulders on either side. The maintenance cost per mile for a gravel road was estimated to $4,160 for a 5-year maintenance cycle with grading done every year and regravelling every 5 years. However, this may vary for regions depending on variations in labor costs per hour, material costs, and equipment usage costs per hour. The study discussed development of an economic analysis to increase the understanding of maintenance cost variations of gravel road surfaces and paved road surfaces for a longer period of time (20 years). With variation in maintenance frequency of major activities for paved surfaces (seal coating) and gravel surfaces (regravelling), maintenance costs per mile per year were calculated. It showed that average annual maintenance costs for a paved road were less than annual maintenance costs of a gravel road for roads with generally high traffic volume. However, this approach did not connect annual maintenance costs for a particular roadway surface type with traffic on that surface. The study also mentioned a few indirect advantages of paved surfaces compared to gravel surfaces, such as elimination of dust problems, decreased VOC, user preference for more comfort, and high economic development status.

Researchers in South Dakota developed a tool to compare costs associated with various roadway surface types to determine the most economical surface type (Zimmerman & Wolters, 2004). Roadway surface types included in the study were HMA (paved) surface, blotter (chip sealed), gravel, and stabilized surface. This study incorporated economic factors such as agency cost (construction cost and maintenance cost) and user cost (VOC), and non-economic factors such as politics, public preferences, and housing density. Agency cost, which included initial construction cost and maintenance cost, was obtained from various local road agencies in South Dakota. Information regarding truck traffic level, name of the road, its type, mileage, and ADT were obtained through the survey. In order to calibrate the methodology to local agencies in South Dakota, all counties in the state were asked to provide data related to specific road sections in their county. An attempt was made to collect data for all road surface types so that a full range of ADT, truck percentage levels, terrains, and subgrade types were represented in model development.

Twenty-three of the 66 counties in the state participated in this South Dakota study. Participating counties were provided with survey forms requesting specific section information, including initial construction costs, maintenance costs and maintenance frequency, and other pertinent information needed to develop agency cost models. In order to develop user cost models, the South Dakota Department of Transportation provided ADT information for each pavement section in the study. After all necessary information was collected from the counties, LCC analysis was conducted on each pavement section using a 20-year analysis period and a 3.5% discount rate to determine the present worth value. One objective of the study was to develop agency cost as a function of roadway surface type. A linear regression method was used to determine whether variables such as surface type, ADT, terrain type, subgrade type, and truck traffic level have statistical significance when calculating the agency cost and VOCs. Results showed that ADT was the only factor that was statistically significant when calculating agency and VOCs on HMA, blotter, and gravel roads. The model showed that when only average agency cost was considered, a gravel roadway surface was the most effective surface type for ADT between 0 and 150 vpd, the chip-sealed surface was effective for ADT values of 150–660 vpd, and the paved surface was effective for ADT values greater than 660 vpd. Results differed by region due to variation in labor, equipment, and material costs and variation in traffic volume data.

Zimmerman and Wolters (2004) determined VOCs using the book *Economic Analysis for Highways* (Winfrey, 1969), which considers surface type, speed and type of vehicle, and roadway characteristics such as gradient and horizontal curves when determining operating costs for all vehicles that utilize the road. The cost was converted to the current value of a dollar for the year of consideration for the study (2003) and used for computation. VOCs were lowest on the paved surface and continued to increase for the chip-sealed surface and gravel surface.

After developing the cost models, the project developed an easy-to-use computerized tool to allow agencies to input local costs and treatments to fit their local conditions (Zimmerman & Wolters, 2004). The computerized tool leads the user through steps to input information about the road section, including project limits and ADT count, and input agency maintenance and construction costs broken down by surface type. It estimated user costs, which were costs to drivers on the roads, and includes VOCs and crash costs associated with roadway surface types. User costs were weighted to give more or less importance in the analysis. After all initial input variables are submitted, the computer program summarizes total costs for building and maintaining each roadway type. The user then inputted other non-economic factors that relate to all surface types, including growth rates for an area, housing concentration, dust control needs, mail route locations, truck traffic, and political considerations. Again, the evaluator was allowed to weight each factor in the analysis according to the local scenario. This tool provided output that is easy to generate and understand. Cost comparisons were computed for several alternatives, and the user has help with selecting appropriate input variables for a typical agency. The results were objective and assist in making a clear comparison between roadway surface types.

In addition to the computerized tool prepared to assist in selecting the most economical alternative under a given set of conditions, previous studies were found regarding software development for decision making for roadway officials having little or no computer background. A study in the Appalachian region (along the spine of the Appalachian Mountains from southern New York to northern Mississippi) developed a microcomputer program to aid decision-making for LVR rehabilitation (Eck, 1987). The objectives of the study were to determine factors relevant to road upgrading and to develop a software-interfaced computer program to help in decision-making. Routine maintenance of roads was carried out every year, but upgrading and rehabilitation was done once in several years. Funds available with the agency were insufficient to upgrade and carry out all rehabilitation processes. Therefore, this study determined factors that are important for consideration and given higher priority while using the funds in proper direction. Critical roadway sections that needed more attention were identified by considering the deteriorating condition of the surface, agency cost information such as construction costs and maintenance costs, traffic information such as ADT and number of lanes, and roadway characteristics such as roadway width, horizontal curves, and drainage. The above factors were considered and a flowchart was developed to address the current scenario and determine the best alternative roadway surface type. Logic from the flowchart was used to develop a microcomputer program. Deficiencies on the roadway surface were identified and inputted into the software, and the software returned various feasible alternatives for upgrading as an output (Eck, 1987).

After all factors are known, the importance of all factors must be determined. A study in Indiana described a procedure to develop weights and scaled values for important factors and to find a final cumulative score for gravel roads and paved roads (Figueroa, Fotsch, Hubbard, & Haddock, 2013). This method determined the least expensive way to maintain roads by suggesting the appropriate roadway surface type. Another paper on multi-criteria decision-making identified the most important or a critical factor for highway safety needs (Dissanayake, Lu, Chu, & Turner, 1999). The proposed method in this study presents how to determine importance of factors. NCHRP Report 703, *Guide for Pavement-Type Selection*, explains detailed steps to be followed to determine pavement type. However, this study applies to major roads and does not discuss LVRs (Hallin et al., 2011). It identifies various important factors and use of LCC analysis to determine the best pavement alternative.

NCHRP Synthesis 485, *Converting Paved Roads to Unpaved*, identified about 70 projects that converted paved roads back to unpaved (Fay, Kroon, Skorseth, Reid, & Jones, 2016). The survey conducted for the project identified 48 local, state, and federal agencies that had 550 miles of road converted to unpaved. The study considered the roads with AADT of 250 vpd or less as a low volume road. The study conducted a nationwide survey to get details about the conversion of roadway surface types. The study mentioned that a gravel road with proper maintenance was safer than a deteriorated paved road. The cost considerations also determined that the sum of conversion cost (paved road to unpaved) and maintenance cost for the unpaved road was less than the maintenance cost for the deteriorated paved road, thus showing economic advantage in the long term.

This section of literature review regarding studies that include maintenance activities and practices on gravel roads versus paved roads provides insight about how to incorporate important factors such as percentage of heavy vehicles and VOCs, etc., along with the traffic volume for determining the roadway surface type. In addition, LCC analysis was widely used to compare agency costs for various roadway surface types.

2.2 Safety Studies on Low-Volume Rural Roads

Various studies have investigated safety-related issues on low-volume rural roads but mostly on a paved surface. One study found that crash rates were higher on LVRs compared to other roads (Zegeer, Stewart, Council, & Neuman, 1994). The study was conducted on a sample of nearly 5,000 miles of paved two-lane rural roads in seven states: Alabama, Michigan, Montana, North Carolina, Utah, Washington, and West Virginia. This study considered roads with traffic volumes less than 2,000 vpd as LVRs and determined a crash rate of 3.5 per million vehicle miles traveled (VMT) on low-volume paved roads compared to a crash rate of 2.4 per million VMT on all high-volume roads. The study determined that fixed-object crashes, rollover crashes, and other run-off-road crashes were more frequent on LVRs. The study, which compared crash rates on paved roads and unpaved roads, was carried out for three ADT groups: ADT less than 250 vpd, ADT between 250 vpd and 400 vpd, and ADT greater than 400 vpd. The 250–400 vpd ADT group and the group with ADT greater than 400 vpd were eventually combined due to the small sample size in the latter group. This study did not observe any significant difference between crash rates on paved and unpaved roads with ADT of 250 vpd or less. However, for ADT greater than 250 vpd, paved roads were found to be significantly safer than unpaved roads. Therefore, the authors suggested that unpaved roads with traffic volume of 250 vpd or greater should be paved.

Limited research has been performed regarding safety issues on low-volume unpaved roads in rural areas. The state of Iowa has a detailed crash and roadway feature database and thus had a unique opportunity to study rural LVR safety (Souleyrette et al., 2010). In addition to evaluating and mitigating safety concerns on low-volume unpaved rural roads in Iowa, one study described a few significant factors in crashes on unpaved roadway sections. The objectives of the study were to identify local roadway segments with higher-than-average crash frequency and consequent probable causes and suggest low-cost safety measures. This study found that crashes near high schools were primarily due to young drivers, many roads did not have clear statutory speed limit signs, and most drivers were not aware of speed limits in unpaved sections (McDonald & Sperry, 2013).

The Iowa study also showed that crash rate is strongly related to traffic volume (Souleyrette et al., 2010). Crash data for 7 years, from 2001 to 2007, was considered for the study. The study also showed that the crash rate was higher on LVRs compared to high-volume roads, thus signifying the magnitude of safety concerns for LVRs. Table 2.1 shows the variation in crash rates per hundred million (10^8) VMT for various ADT groups. The overall crash rate for all county roads in Iowa was 174 crashes per hundred million VMT. The study also showed that crash rates depend on the type of roadway surface: unpaved roads generally exhibited higher crash rates than paved roads. The study considered crash rates within various ADT groups for unpaved roads and paved roads for all county roads in Iowa. Table 2.2 compares crash rates on unpaved and paved roads for ADT group distributions.

For all ADT groups, crash rates were higher on unpaved roads than on paved roads; however, crash rates on unpaved roads were significantly higher than paved roads with ADT of 100 vpd or more. Thus, the authors recommended that safety needs on unpaved roads with traffic volumes of 101 to 400 vpd be prioritized.

Table 2.1: Variation in Crash Rates with ADT Group Distributions

a. ADT Group Distribution 1

ADT groups (vpd)	0–100	101–400	401–1,000	1,001–13,500
Crash rate (10^8 VMT)	257	198	147	137

b. ADT Group Distribution 2

ADT groups (vpd)	0–100	101–400	401–13,500
Crash rate (10^8 VMT)	257	198	142

c. ADT Group Distribution 3

ADT groups (vpd)	0–100	101–1,000	1,001–13,500
Crash rate (10^8 VMT)	257	166	137

d. ADT Group Distribution 4

ADT groups (vpd)	0–400	401–1,000	1,001–13,500
Crash rate (10^8 VMT)	227	147	137

e. ADT Group Distribution 5

ADT groups (vpd)	0–400	401–13,500	0–1,000	1,001–13,500
Crash rate (10^8 VMT)	227	142	190	137

Source: Souleyrette et al. (2010)

Table 2.2: Comparison of Crash Rates on Unpaved and Paved Roads for ADT Groups

ADT groups (vpd)		0–100	101–400	401–1,000	0–400	0–1,000	0–13,500
Crash rate (10^8 VMT)	Unpaved roads	257	318	169	270	269	267
	Paved roads	255	156	147	159	151	146

Source: Souleyrette et al. (2010)

Another study compared injury crash rates on unpaved road sections in Albany County, Wyoming, to injury crash rates on all roads in the state. Results of the study showed increased crash severity on low-volume rural roads. Because rural roads include paved and unpaved roads, specific crash trends for unpaved roads are generally not available. This study found that the injury crash rate on selected Wyoming unpaved road sections was five times higher than for all the other roads within the state (Caldwell & Wilson, 1999). However, the study was carried out on a small sample of road sections and crashes. In another Wyoming study in 2009, road surface type was found to be insignificant for predicting crashes on high-risk rural roads, meaning that crash rates on gravel-surface roads and paved-surface roads had statistically similar crash rates (Ksaibati, Zhong, & Evans, 2009).

This section of literature review regarding safety-related studies on LVRs highlighted that, in general, paved roads are safer than gravel roads. A similar safety study in Kansas was conducted for this research using the knowledge from the mentioned literature; all the reviewed literature studies were closely related to this research study in Kansas. Using the reviewed studies with modifications for local Kansas conditions, a proposed methodology (explained in Chapter 4) was used to determine a safe roadway surface type and eventually use it as a guideline for determining a better roadway surface type.

Chapter 3: Data Collection

This chapter discusses all data collected for the study and data collection procedures. In order to achieve the objectives of this research, data collections were performed using two approaches: data collection through surveys and data collection from Kansas counties. The following section discusses the data collected using each method and how that data was used for guideline development.

3.1 Data Collection through Surveys

Every state has unique methods for maintenance of local rural roads, and even within a state, each county distinctively performs maintenance activities on their local roads. Surveys were carried out to understand maintenance practices on local rural roads, primarily gravel roads and paved roads. The two surveys conducted included an out-of-state survey and a Kansas county survey.

3.1.1 Out-of-State Survey

The purpose of this survey was to identify any guidelines regarding conversion of roadway surface type in states other than Kansas. The out-of-state survey was conducted for the following purposes:

- To identify maintenance practices on local gravel roads and paved roads, and
- To determine if states have criteria or specific guidelines for converting local gravel roads into paved roads or vice versa.

The survey questionnaire included questions to determine if other states follow standards to convert a gravel road to paved road or vice versa. Another question was to identify any possible need for change or improvement in geometry of the road, such as cross section or horizontal and vertical curves, while converting from one surface type to another. Factors that seemed important while considering roadway surface type conversion were ranked on a 5-level Likert scale by respondents. Similar importance was recorded for factors related to roadway surface characteristics during a conversion. A copy of the survey questionnaire is provided in Appendix B.

Contact information for local officials closely looking into local rural roads was obtained through the National Association of County Engineers (NACE, 2014) website and the Department of Transportation (DOT) website of each state. The survey questionnaire was circulated in two forms with the intention of achieving high response rate. Initially, a macro-based Microsoft Word document was emailed to respective officials who oversee the maintenance of local rural roads. Later, a web link to the online survey form was emailed to officials to allow ease of response. Officials from many states did not respond to the survey, but a few states had multiple responses from various county officials within the same state. Figure 3.1 shows the states that responded to the survey and Table 3.1 shows the number of responses from each state.

Sixty-two responses were collected from 17 states other than Kansas with at least one reply from those states. Out of the 17 states that responded, 11 states (65%) had no standards for improvement, and seven states (41%) stated that roadway surface type conversion could be done without improvement of road cross sections or roadway alignment. The states of Iowa, Minnesota, Louisiana, and California said that the minimum right-of-way should be 24 ft when converting a gravel road to a paved road and the speed limit on paved roads should be determined per the *Manual on Uniform Traffic Control Devices* (MUTCD; FHWA, 2009). According to survey responses, traffic volume was one of the main driving factors to cause roadway surface conversion. However, getting many useful details could not be achieved from the out-of-state survey.

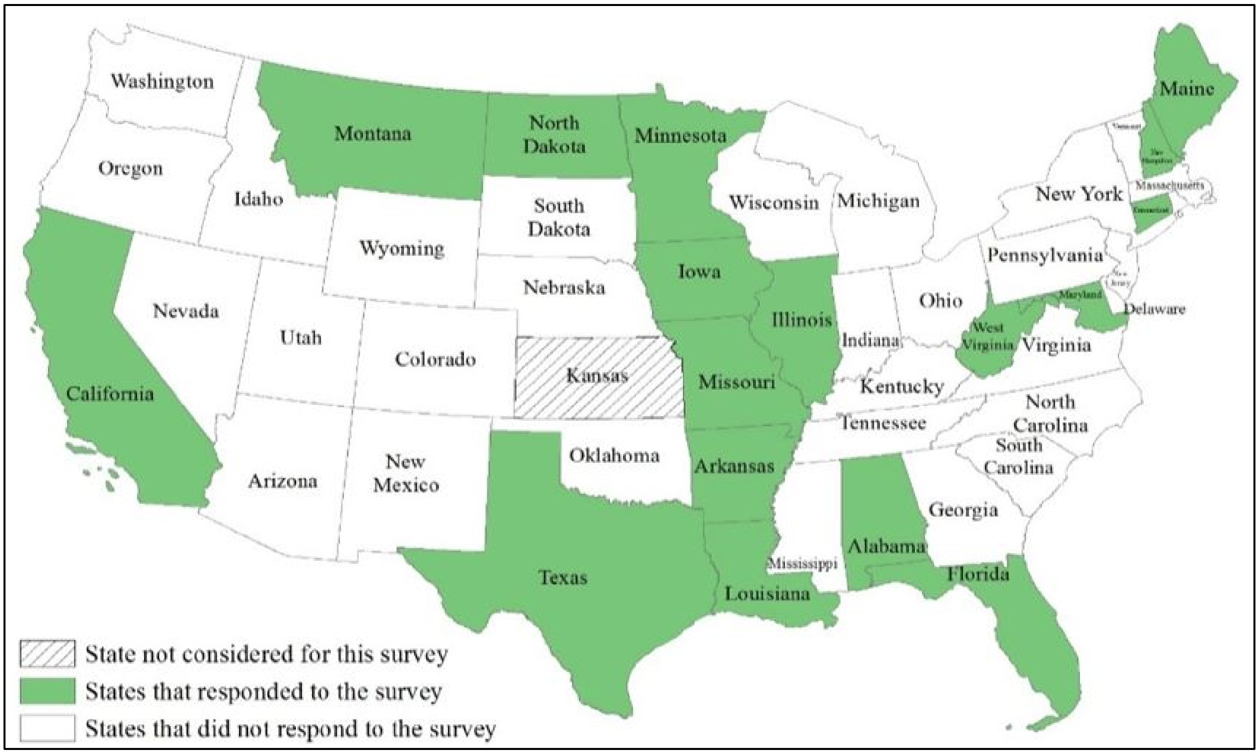


Figure 3.1: US States that Completed the Out-of-State Survey

Table 3.1: Number of Survey Responses per State

No.	State	Survey responses
1	Alabama	1
2	Arkansas	15
3	California	8
4	Connecticut	1
5	Florida	1
6	Illinois	1
7	Iowa	16
8	Louisiana	5
9	Maine	1
10	Maryland	1
11	Minnesota	6
12	Missouri	1
13	Montana	1
14	New Hampshire	1
15	North Dakota	1
16	Texas	1
17	West Virginia	1
	TOTAL	**62**

3.1.2 Kansas County Survey

In order to increase the understanding of roadway conditions and maintenance practices specific to Kansas, a modified survey questionnaire was prepared for Kansas counties. The survey for Kansas counties was conducted for the following purposes:

- To understand maintenance practices on local gravel roads and paved roads at the county level, and
- To identify counties that keep project-level detailed information on maintenance activities and costs of gravel and paved roads, traffic volume information, etc.

A copy of the survey questionnaire for Kansas counties is provided in Appendix B.

The survey questionnaire was distributed to county officials in all 105 counties in Kansas. Contact information was obtained from the KDOT website (KDOT, 2014) or the Kansas County Highway Association (KCHA) website (KCHA, 2014). The survey questionnaire was distributed through the following mediums in order to maximize the response rate:

- Emails with a macro-enabled Microsoft Word document, allowing county officials to mark an appropriate option and resend the document with a recorded response.
- Emails with an online survey link, enabling county officials to select an appropriate option and submit directly-recorded answers online; reply to the email was not required.
- Fax the survey questionnaire to counties if email contact information was incorrect or if email was not functional.
- Mail the survey questionnaire and retrieve responses through a self-addressed stamped envelope, resulting in acquisition of additional responses.

All the mentioned approaches to obtain survey responses resulted in survey responses from 77 out of the 105 counties which yielded a response rate of 74%. Figure 3.2 shows the breakdown in percentages based on the approach utilized by respondents. Figure 3.3 shows Kansas counties that responded to the survey.

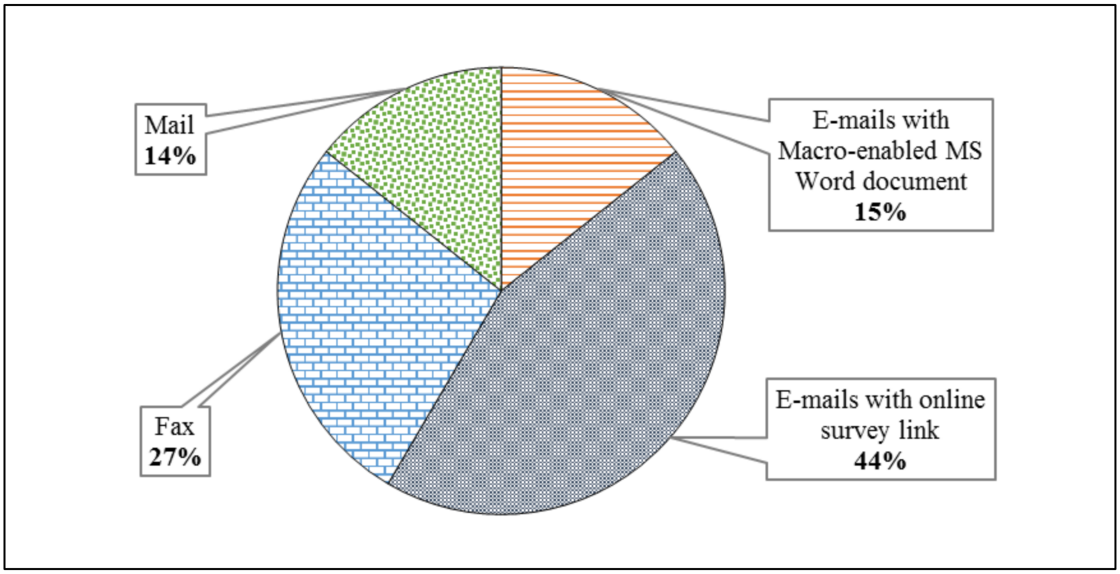


Figure 3.2: Survey Responses from Kansas Counties Based on Approach Utilized

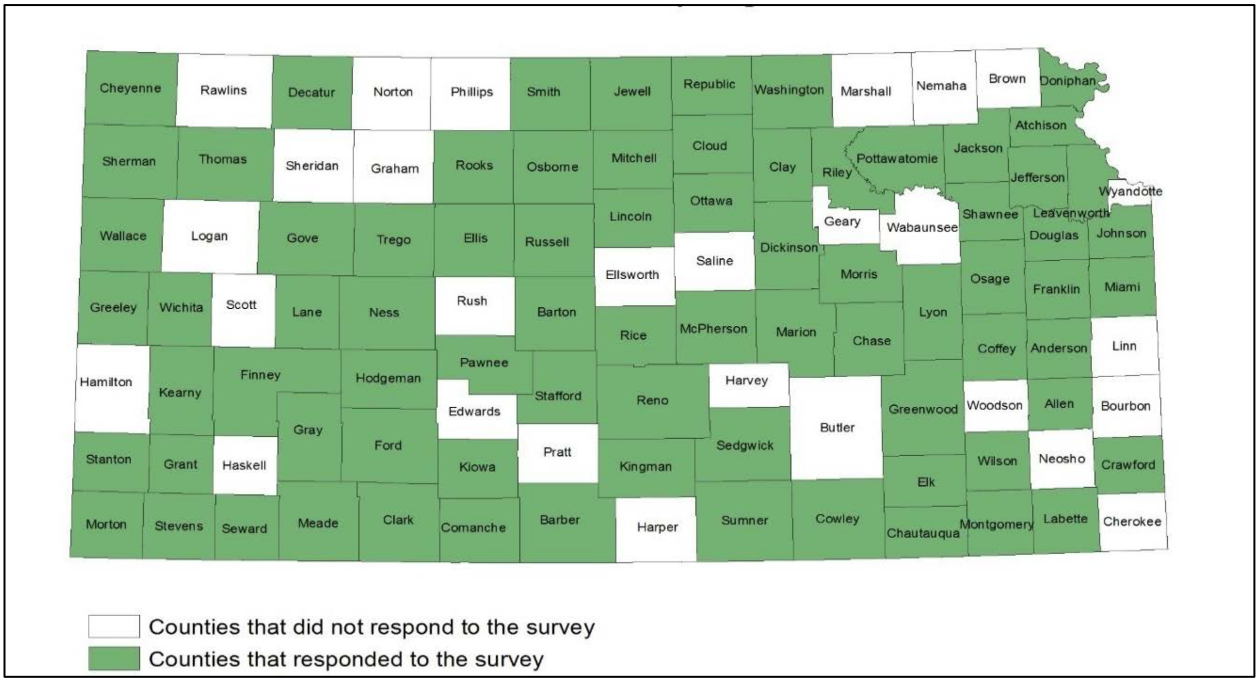


Figure 3.3: Kansas Counties that Completed the Survey

Importance of factors when considering roadway surface conversion was recorded using the Likert scale, the most widely used scaling approach for surveys that maintains uniform distance between available options (Likert, 1932). The subjective opinion for each question was uniformly spread on a 5-point scale with a neutral middle option. Scaled value was also calculated to bring all collected responses to the same level of comparison. Response counts for rating the importance of factors while considering conversion is shown in Table 3.2. Figure 3.4 and Figure 3.5 graphically represent the response counts.

Table 3.2: Survey Responses Rating the Importance of Factors Considered for Conversion

Importance of the following factors:		Number of counties with response as						
		A	B	C	D	E	No response	Total
1.	Initial construction cost	52	17	4	0	1	3	77
2.	Maintenance cost	45	22	4	2	1	3	77
3.	ADT	27	36	6	4	1	3	77
4.	Safety	40	24	7	1	1	4	77
5.	Frequency of maintenance	20	40	10	1	2	4	77
6.	Drainage	19	23	18	9	2	6	77
7. Purpose of road usage	Heavy vehicle route	38	26	7	2	1	3	77
	Retail and commercial route	19	36	15	2	2	3	77
	Parks and community route	8	24	28	10	4	3	77
	Government facility route	10	23	30	7	4	3	77
	School route	16	28	24	3	3	3	77
	Farm-to-market route	6	18	28	16	6	3	77
	Church route	12	21	22	16	3	3	77
	Residential mail route	24	27	17	3	2	4	77

NOTE:
1) A: Very Important B: Important C: Moderately Important D: Less Important E: Not Important
2) A few counties left few fields unmarked/unchecked; those responses are listed under the column "No response."

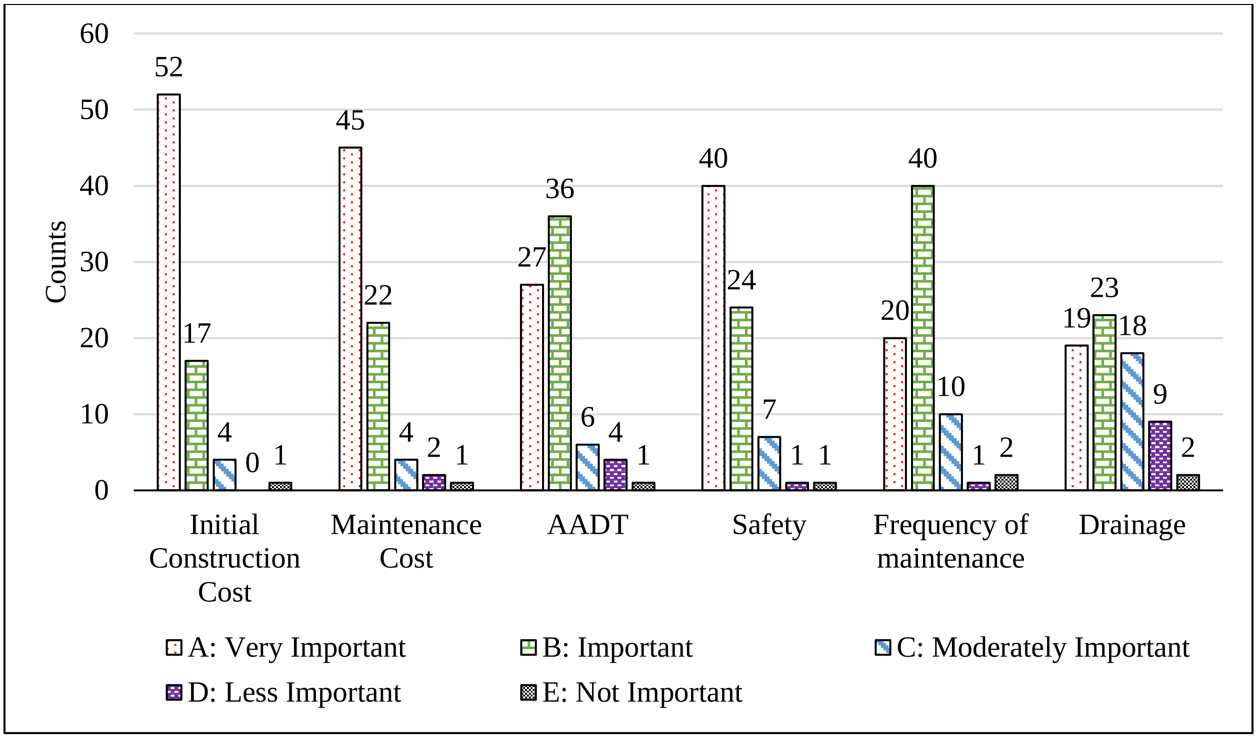


Figure 3.4: Survey Responses for Each Critical Factor

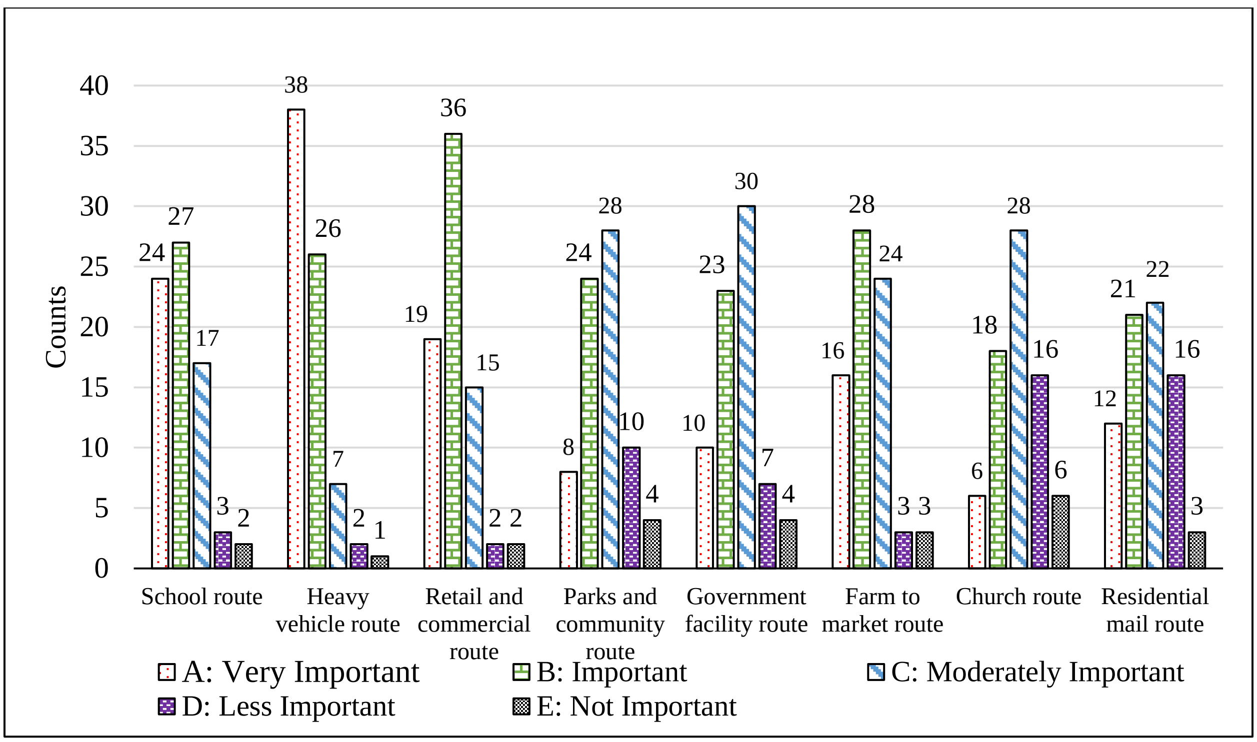


Figure 3.5: Survey Responses for Purpose of Road Usage

These counts were converted to scaled values using the respective scores for each selected option in order to identify the relative importance of factors. Scaling used for the survey was noted as A for “Very Important” (score of 1.00), B for “Important” (score of 0.75), C for “Moderately Important” (score of 0.50), D for “Less Important” (score of 0.25), and E for “Not Important” (score of 0.00). Each response was decoded using the corresponding score, and the scaled value was calculated using Equation 3.1.

$$S = \frac{\sum_{i=1}^{n} C_i \times s_i}{N} \quad \textbf{Equation 3.1}$$

Where:

S = scaled value for each factor

n = number of categories of importance (n = 5)

C_i = counts of each factor for respective n

s_i = score for each factor for respective n

N = total number of responses

For example, the scaled value for initial construction cost was calculated using Equation 3.1, as follows:

$$S = \left(\frac{52 \times 1.00 + 17 \times 0.75 + 4 \times 0.50 + 0 \times 0.25 + 1 \times 0.00}{74}\right) = 0.90$$

Figure 3.6 and Figure 3.7 graphically show the scaled values of all factors. A higher scaled value close to 1.0 means that the factor was more important; therefore, that factor was given high priority when considering a roadway surface conversion. For the scaled values for critical factors, initial construction cost was the most important factor, followed by maintenance cost and safety, when deciding the most suitable type of roadway surface.

The scaled values were used in the methodology for guideline development in order to determine the appropriate roadway surface type.

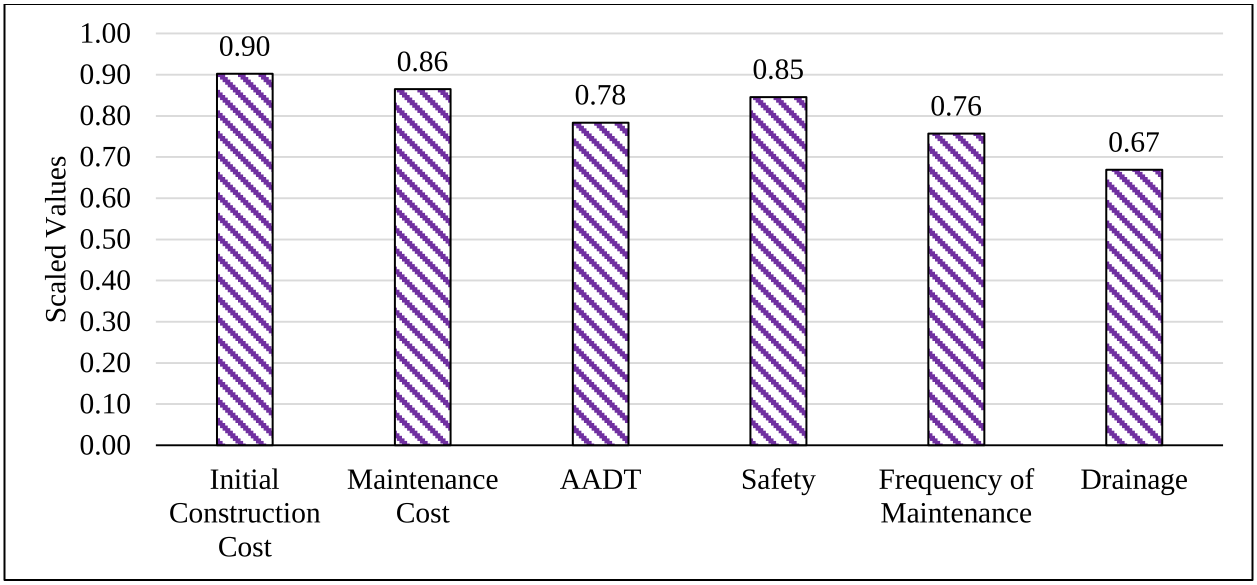


Figure 3.6: Scaled Values of Critical Factors

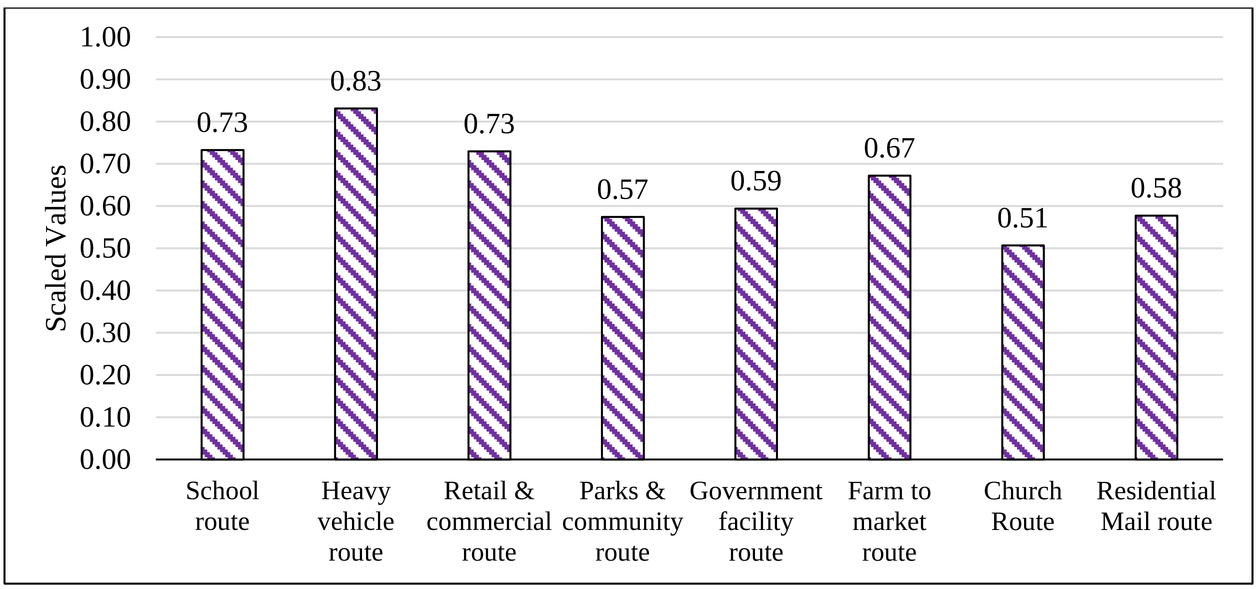
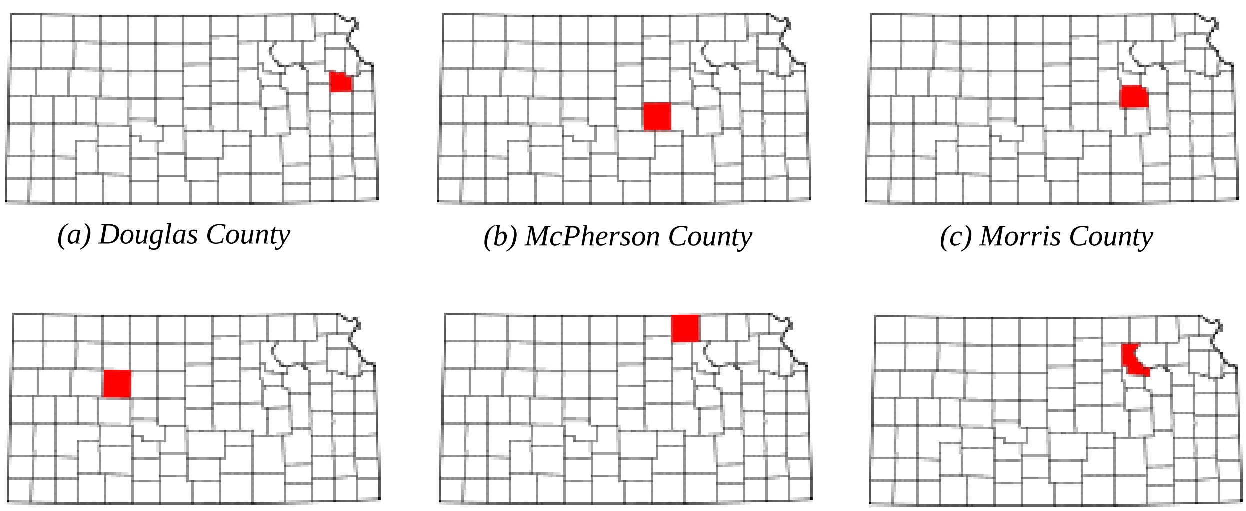


Figure 3.7: Scaled Values for Route Based on Purpose of Road Usage

3.2 Detailed Data Collection from Kansas Counties

Survey responses revealed the counties that had detailed project-level information such as maintenance activities carried out on county roads, cost of maintenance activities, maintenance frequency, surface type, and traffic volume. Out of the 77 counties that responded to the survey, 49 counties (64%) had project-level information such as construction cost, maintenance cost, ADT, and types of improvement. However, only 35 of those counties (45%) agreed to provide that information for this research. After contacting the 35 counties again through emails or phone calls, results showed that not all the counties had broken down their maintenance costs by section or route. The information available from most of those counties was similar to that provided for the county annual report in which total county costs spent on all county-maintained roads were reported (KDOT, 2013). Six counties had information that was used to identify trends in maintenance activities for this research. The geographical distribution and variation of percentage of gravel roads and paved roads in the six counties negated any biased findings. The six counties were Douglas County, McPherson County, Morris County, Riley County, Trego County, and Washington County. These counties provided detailed information regarding maintenance on rural local road sections for the past 3 to 5 years, although the manner in which each county tracked the details differed. Detailed maintenance trends for local gravel and paved roads are mentioned in following sections in this chapter. Figure 3.8 shows the location of these six counties.



(a) Douglas County *(b) McPherson County* *(c) Morris County*

(d) Trego County *(e) Washington County* *(f) Riley County*

Figure 3.8: Geographical Locations of Six Counties Selected for Further Study

Three types of road systems are used in Kansas for roads outside of cities (Kansas Local Technical Assistance Program, 2011). The non-county unit road system (county township system) requires the county to maintain main (primary) roads and townships to maintain local (secondary) roads. Thirty-five counties in Kansas are categorized under this road system. The county unit road system requires the county to maintain all public roads outside the cities; township is not responsible for any road maintenance. Sixty-seven counties in Kansas are categorized under this road system. The general county rural highway system (county-rural system) is similar to the county unit road system in that each county maintains all public roads outside cities and townships have no maintenance responsibilities. However, in the county-rural system, the county has two funds, one for the main county roads and one for what were previously township roads. Only three counties in Kansas are categorized under this road system.

Among the six counties selected for further study, Douglas County, McPherson County, Riley County, and Washington County are classified under county township road system. Trego County and Morris County are classified under county unit road system. The mileages of gravel roads and paved roads maintained by the respective six counties, shown in Table 3.3, were based on information provided in the *Summary of County Engineers' Annual Reports* (KDOT, 2013).

Table 3.3: Distribution of Miles of Gravel and Paved Roads Maintained by Each of the Six Selected Counties

County	Gravel Miles	Paved Miles	Other Miles	Total Miles
Douglas County	34 (16.3%)	173 (83.2%)	1 (0.5%)	208 (100%)
McPherson County	54 (14.9%)	293 (80.9%)	15 (4.1%)	362 (100%)
Riley County	109 (46.2%)	124 (52.5%)	3 (1.3%)	236 (100%)
Washington County	240 (80.0%)	60 (20.0%)	0 (0.0%)	300 (100%)
Morris County	979 (87.3%)	99 (8.8%)	43 (3.8%)	1,121 (100%)
Trego County	792 (72.5%)	0 (0.0%)	300 (27.5%)	1,092 (100%)

Source: KDOT (2013)

Morris County and Trego County are classified under county unit road system, with a higher percentage of gravel roads and very little or no paved roads. Washington County comes under county township road system with high percentage of gravel roads and low percentage of paved roads, whereas Douglas County, McPherson County, and Riley County come under county township road system but with higher percentages of paved roads than gravel roads.

Therefore, the six selected counties demonstrated good variation in regards to percentage of roadway surface type within the counties and variation in classifications of road systems. Each county functions differently from one another. Maintenance activities were carried out depending on the treatment need for a particular roadway type or regular annual maintenance, depending on the county budget. AADT information for each section was obtained from only three out of the six counties. Details of each county are described in the following sections.

3.2.1 Douglas County

In the year 2013, Douglas County had a total of 208 miles of county-maintained roads, not including roads maintained by the townships, consisting of 1 mile (0.48%) of concrete road, 173 miles (83.17%) of asphalt roads, and 34 miles (16.35%) of gravel roads.

Douglas County provided complete project level details of all maintenance work on main roads from the years 2010 to 2013. Project-level details for routes with 2 miles of length to 10 miles of length were provided. Maintenance details from 2010 to 2013 for eight routes, including four paved routes and four gravel sections, are shown in Table 3.4 and Table 3.5, respectively.

The county provided traffic volume details on these sections obtained using traffic count devices. A Douglas County map for the years 2010–2013 showed all sections of paved and gravel roads and the AADT on each sections. Traffic counting was accomplished annually by setting the traffic counter at the same or different locations. Many traffic count locations were also included along one route to allow the traffic count to be averaged and a single AADT value for each route was obtained. The maintenance cost per mile differed for each section each year because not all maintenance activities occurred during any particular year. In Douglas County, regravelling activity on gravel roads is done every year, and chip sealing is done every 3–4 years for roads with high traffic volume and every 6–7 years for roads with less traffic volume. Overlay on paved roads is applied every 10 years. The overall average maintenance cost was $3,794 per mile for paved roads and $10,428 per mile for gravel roads.

Table 3.4: Maintenance Costs and AADT of Paved Sections in Douglas County (2010–2013)

	Project No.	Miles of road in the route	Year	Maintenance cost for entire route	Maintenance cost/mile	AADT (vpd)
1	1055-2	7	2010	$63,142	$9,020	2,708
			2011	$35,600	$5,086	3,210
			2012	$24,881	$3,554	2,858
			2013	$22,906	$3,272	3,394
2	1057	7	2010	$56,510	$8,073	1,282
			2011	$6,539	$934	1,400
			2012	$5,313	$759	803
			2013	$6,111	$873	1,132
3	1061-2	10	2010	$51,161	$5,116	1,890
			2011	$4,488	$449	1,668
			2012	$890	$89	2,131
			2013	$11,336	$1,134	1,541
4	1029-1	9.5	2010	$47,414	$4,991	608
			2011	$5,665	$596	604
			2012	$44,899	$4,726	548
			2013	$114,252	$12,027	499

Table 3.5: Maintenance Costs and AADT of Gravel Sections in Douglas County (2010–2013)

	Project No.	Miles of road in the route	Year	Maintenance cost for entire route	Maintenance cost/mile	AADT (vpd)
1	458-1	3.5	2010	$85,559.00	$24,445	113
			2011	$57,288.00	$16,368	194
			2012	$39,172.00	$11,192	104
			2013	$32,312.00	$9,232	128
2	474	2	2010	$27,495.00	$13,748	44
			2011	$7,575.00	$3,788	40
			2012	$11,301.00	$5,651	13
			2013	$11,249.00	$5,625	25
3	1023-1	7	2010	$70,459.00	$10,066	58
			2011	$31,317.00	$4,474	55
			2012	$89,574.00	$12,796	48
			2013	$54,470.00	$7,781	44
4	1039-1	2.5	2010	$31,420.00	$12,568	117
			2011	$16,846.00	$6,738	150
			2012	$44,132.00	$17,653	62
			2013	$11,807.00	$4,723	78

3.2.2 McPherson County

In the year 2013, McPherson County had a total of 362 miles of county-maintained roads, consisting of 15 miles (4%) of concrete roads, 293 miles (81%) of asphalt roads, and 54 miles (15%) of gravel roads. The county provided their public works annual report for the years 2011, 2012, and 2013, including maintenance details and all activities carried out by the county on county bridges and roads during each year. McPherson County typically does not carry out any traffic counts studies. Because this county primarily contains asphalt roads (81%) and the limited gravel road mileage is well maintained, no gravel roads needed to be converted to paved. However, at the request of a local commercial business, approximately 1.3 miles of gravel road were converted to paved road for $828,500 in 2010. Maintenance costs of gravel roads are slightly higher in McPherson County because the gravel roads are scattered throughout the county in small sections, thereby increasing the equipment cost per mile due to transporting equipment to the gravel section and back to the county main office.

Table 3.6, Table 3.7, and Table 3.8 show maintenance activities and maintenance costs for the years 2011, 2012, and 2013, respectively.

All major maintenance activities are recorded by McPherson County on their individual routes. The average cost for HMA overlay is approximately $104,000 per mile; average cost for chip sealing is $18,200 per mile; average cost for crack sealing and patching and stabilizing is $11,700 per mile; and the average cost for blading, resurfacing, and spot/regravelling is $4,800 per mile.

Table 3.6: Maintenance Details for McPherson County (2011)

No.	Route	Total mileage of route	Activity	Miles	Total cost	Cost/mile
1	CR699	14.00	HMA overlay	4.62	$535,608	$115,932
2	CR304	30.00	Chip sealing	7.89	$123,678	$15,675
3	CR447	20.00	Chip sealing	0.41	$8,986	$21,917
4	CR446	22.00	Chip sealing	9.90	$142,959	$14,440
5	CR444	12.00	Chip sealing	4.23	$63,571	$15,029
6	CR1064	6.00	Chip sealing	3.09	$67,255	$21,765
7	CR450	3.00	Chip sealing	2.98	$65,253	$21,897
8	CR1067	5.00	Chip sealing	2.85	$48,863	$17,145
9	CR1961	13.00	Crack sealing	2.50	$3,333	$1,333
10	CR429	13.50	Crack sealing, patching	13.50	$34,454	$2,552
11	CR445	27.00	Patching, stabilizing	4.00	$203,488	$50,872
12	CR319	27.00	Patching, stabilizing	4.00	$14,620	$3,655
13	CR307	14.00	Patching, stabilizing	10.00	$2,761	$276
14	CR444	12.00	Crack sealing, patching, stabilizing	3.50	$59,415	$16,976
15	CR1064	6.00	Crack sealing, patching, stabilizing	2.00	$97,829	$48,915
16	CR444	12.00	Blading, resurfacing, spot/regravelling	9.00	$19,457	$2,162
17	CR1786	3.00	Blading, resurfacing	3.00	$4,016	$1,339
18	CR1067	5.00	Blading, resurfacing	2.00	$5,453	$2,727
19	CR319	27.00	Blading, resurfacing, spot/regravelling	7.00	$20,879	$2,983
20	CR1068	8.00	Blading, resurfacing, spot/regravelling	8.00	$24,188	$3,024
21	CR1771	8.00	Blading, resurfacing, spot/regravelling	7.00	$18,393	$2,628
22	CR426	9.00	Blading, resurfacing, spot/regravelling	6.00	$16,122	$2,687

NOTE: The entire route may not contain the same road surface. For example, CR 319 was a 27-mile section that was asphalt surfaced and gravel surfaced. Patching and stabilizing were done on 4 miles of an asphalt section and blading, resurfacing, spot gravelling or regravelling was done on 7 miles of a gravel section; no major road maintenance activities were done on the remaining 16 miles of CR 319 in the year 2011.

Table 3.7: Maintenance Details for McPherson County (2012)

No.	Route	Total mileage of route	Activity	Miles	Total cost	Cost/mile
1	CR445	27.00	HMA overlay	4.00	$359,436	$89,859
2	CR699	14.00	HMA overlay	1.00	$106,283	$106,283
3	CR1073	1.50	Chip sealing	1.28	$27,711	$21,649
4	CR1073	1.50	Chip sealing	1.24	$22,462	$18,115
5	CR1065E	1.50	Chip sealing	1.47	$29,890	$20,333
6	CR319	27.00	Chip sealing	6.09	$102,872	$16,892
7	CR307	14.00	Chip sealing	6.06	$15,532	$2,563
8	CR1065W	18.50	Chip sealing	8.67	$146,834	$16,936
9	CR448	16.00	Chip sealing	4.88	$89,688	$18,379
10	CR446	22.00	Crack sealing	4.00	$9,531	$2,383
11	CR451	16.00	Crack sealing	3.00	$7,061	$2,354
12	CR421	3.00	Crack sealing	3.00	$3,399	$1,133
13	CR319	27.00	Crack sealing	2.00	$1,617	$809
14	CR307	14.00	Crack sealing	2.00	$2,254	$1,127
15	CR448	12.00	Crack sealing	5.00	$3,339	$668
16	CR307	14.00	Crack sealing	6.00	$6,104	$1,017
17	CR1065	20.00	Crack sealing	3.00	$12,274	$4,091
18	CR1065	20.00	Patching, stabilizing	10.00	$189,059	$18,906
19	CR1065	20.00	Patching, stabilizing	2.00	$47,312	$23,656
20	CR448	12.00	Patching, stabilizing	4.00	$36,501	$9,125
21	CR304	30.00	Patching, stabilizing	7.00	$69,871	$9,982
22	CR319	27.00	Patching, stabilizing	4.00	$418,525	$104,631
23	CR304	30.00	Patching, stabilizing	16.00	$85,170	$5,323
24	CR429	13.50	Patching, stabilizing	14.00	$176,058	$12,576
25	CR319	27.00	Blading, resurfacing, spot/regravelling	7.00	$21,754	$3,108
26	CR426	9.00	Blading, resurfacing, spot/regravelling	6.00	$27,252	$4,542
27	CR444	12.00	Blading, resurfacing, spot/regravelling	9.00	$29,676	$3,297
28	CR1067	5.00	Blading, resurfacing, spot/regravelling	2.00	$8,399	$4,200
29	CR1068	8.00	Blading, resurfacing, spot/regravelling	7.00	$112,269	$16,038
30	CR1069	10.00	Blading, resurfacing, spot/regravelling	9.00	$58,019	$6,447
31	CR1771	8.00	Blading, resurfacing, spot/regravelling	3.00	$23,423	$7,808
32	CR1786	3.00	Blading, resurfacing, spot/regravelling	3.00	$8,440	$2,813

Table 3.8: Maintenance Details for McPherson County (2013)

No.	Route	Total mileage of route	Activity	Miles	Total cost	Cost/mile
1	CR319	27.00	HMA overlay	6.00	$742,155	$123,692
2	CR445	27.00	HMA overlay	4.00	$395,673	$98,918
3	CR699	14.00	HMA overlay	6.00	$529,367	$88,228
4	CR699	14.00	Chip sealing	7.90	$166,326	$21,054
5	CR1064	6.00	Chip sealing	5.90	$101,291	$17,168
6	CR445	27.00	Chip sealing	5.60	$93,140	$16,632
7	CR307	14.00	Chip sealing	5.90	$85,408	$14,476
8	CR1065	20.00	Chip sealing	9.30	$173,996	$18,709
9	K-61	17.00	Chip sealing	0.20	$7,560	$37,801
10	CR319	27.00	Chip sealing	1.85	$29,883	$16,153
11	CR304	30.00	Chip sealing	17.60	$279,376	$15,874
12	CR1064	6.00	Crack sealing	6.00	$1,506	$251
13	CR447	20.00	Crack sealing	7.00	$912	$130
14	CR594	4.00	Crack sealing	3.00	$534	$178
15	CR448	12.00	Crack sealing	12.00	$3,384	$282
16	CR443	14.00	Crack sealing	9.00	$5,107	$567
17	CR2031	3.00	Crack sealing	2.00	$1,570	$785
18	CR1063	15.00	Patching, stabilizing	6.00	$12,368	$2,061
19	CR446	22.00	Patching, stabilizing	4.00	$62,702	$15,676
20	CR305	12.00	Patching, stabilizing	8.00	$27,179	$3,397
21	CR307	14.00	Patching, stabilizing	4.00	$85,664	$21,416
22	CR429	13.50	Patching, stabilizing	10.50	$169,379	$16,131
23	CR445	27.00	Patching, stabilizing	13.00	$180,454	$13,881
24	CR319	27.00	Blading, resurfacing, spot/regravelling	7.00	$26,726	$3,818
25	CR426	9.00	Blading, resurfacing, spot/regravelling	9.50	$41,897	$4,410
26	CR444	12.00	Blading, resurfacing, spot/regravelling	9.00	$35,203	$3,911
27	CR1067	5.00	Blading, resurfacing, spot/regravelling	2.00	$16,250	$8,125
28	CR1068	8.00	Blading, resurfacing, spot/regravelling	8.00	$64,375	$8,047
29	CR1069	10.00	Blading, resurfacing, spot/regravelling	10.00	$57,562	$5,756
30	CR1786	3.00	Blading, resurfacing, spot/regravelling	3.00	$14,637	$4,879
31	CR1771	8.00	Blading, resurfacing, spot/regravelling	6.50	$33,278	$5,120

3.2.3 Riley County

In the year 2013, Riley County had a total of 236 miles of county-maintained roads, consisting of 3 miles (1%) of concrete roads, 124 miles (53%) of asphalt roads, and 109 miles

(46%) of gravel roads. Table 3.9 shows the details of maintenance and AADT for paved routes. Table 3.10 shows the details of maintenance and AADT for gravel routes.

Table 3.9: Maintenance Costs per Mile of 35 Paved Routes in Riley County (2010–2014)

No.	Routes	Maintenance Cost/Mile						Avg. AADT
		2010	2011	2012	2013	2014	Average	
1	362E	$4,360	$2,982	$123,348	$3,251	$7,343	$28,257	-
2	376	$3,084	$30,337	$10,939	$79,608	$23,031	$29,400	120
3	378	$4,853	$22,627	$8,057	$18,930	$9,498	$12,793	321
4	384W	$149,952	$3,800	$3,857	$5,910	$10,193	$34,742	67
5	388	$27,304	$5,537	$9,690	$5,603	$9,610	$11,549	566
6	390	$21,348	$4,585	$7,522	$5,825	$7,779	$9,412	508
7	392	$6,487	$4,857	$28,508	$6,225	$9,021	$11,020	561
8	396C	$7,326	$5,870	$6,705	$6,727	$8,837	$7,093	572
9	396E	$4,830	$21,033	$102,142	$8,946	$8,938	$29,178	113
10	396W	$3,490	$3,982	$30,310	$8,551	$7,833	$10,833	980
11	406	$25,538	$16,441	$5,367	$15,318	$14,487	$15,430	3,133
12	408	$27,013	$17,331	$16,739	$6,468	$9,545	$15,419	6,443
13	410E	$24,437	$2,304	$871	$2,740	$13,367	$8,744	547
14	412	$4,462	$7,906	$5,526	$7,148	$122,074	$29,423	1,688
15	416	$18,439	$3,671	$1,057	$6,384	$13,914	$8,693	1,115
16	418	$137,923	$5,153	$11,574	$9,817	$7,647	$34,423	745
17	420	$580,910	$516,328	$784,431	$65,171	$113,259	$412,020	1,246
18	420WCC	$5,307	$9,144	$7,897	$14,084	$20,103	$11,307	-
19	424	$7,613	$3,971	$31,313	$4,307	$10,355	$11,512	193
20	873	$2,622	$3,842	$189,237	$8,035	$7,062	$42,160	78
21	875N	$2,946	$21,347	$4,012	$8,538	$5,834	$8,535	241
22	885N	$126,164	$7,098	$5,053	$4,300	$26,467	$33,816	416
23	885S	$31,821	$8,384	$17,469	$5,197	$8,973	$14,369	110
24	887S	$12,550	$4,811	$3,625	$7,836	$7,570	$7,278	274
25	891	$10,112	$21,702	$96,503	$5,616	$11,951	$29,177	175
26	893	$22,866	$6,024	$4,887	$6,862	$7,702	$9,668	176
27	895S	$3,612	$11,523	$75,781	$6,711	$8,685	$21,262	275
28	897S	$18,365	$52,533	$57,200	$18,715	$6,694	$30,701	425
29	901N	$11,623	$4,305	$2,846	$6,108	$7,324	$6,441	-
30	901S	$19,518	$87,430	$4,804	$8,710	$15,149	$27,122	1,406
31	903	$6,101	$4,156	$36,847	$7,923	$6,759	$12,357	2,075
32	903S	$5,467	$14,639	$3,191	$109,733	$8,099	$28,226	515
33	905	$3,614	$10,104	$476,226	$27,053	$9,226	$105,244	922
34	911	$127,557	$9,820	$5,196	$9,940	$11,502	$32,803	363
35	917	$4,780	$9,369	$36,358	$12,079	$12,216	$14,960	301

Table 3.10: Maintenance Costs per Mile of 28 Gravel Routes in Riley County (2010–2014)

No.	Routes	Maintenance cost/mile						Avg. AADT
		2010	2011	2012	2013	2014	Average	
1	362E	$4,858	$7,650	$7,697	$5,577	$7,031	$6,563	46
2	362W	$7,737	$6,324	$8,720	$7,929	$8,366	$7,815	58
3	384E	$6,087	$9,809	$4,757	$17,457	$3,983	$8,418	75
4	384W	$6,430	$5,984	$5,866	$7,983	$6,505	$6,554	53
5	390	$7,943	$10,794	$6,729	$11,738	$6,579	$8,757	109
6	392	$7,815	$6,083	$7,240	$10,590	$6,976	$7,741	74
7	394	$10,760	$4,161	$4,852	$7,154	$3,720	$6,129	41
8	396E	$2,593	$3,589	$3,588	$3,925	$3,269	$3,393	-
9	402	$1,965	$4,552	$1,442	$4,362	$2,278	$2,920	51
10	416	$1,294	$5,145	$2,888	$16,680	$3,081	$5,818	-
11	421	$11,336	$22,836	$10,953	$12,309	$17,513	$14,989	72
12	422	$8,779	$4,679	$3,418	$7,865	$5,879	$6,124	95
13	424	$3,221	$5,516	$2,726	$6,740	$4,577	$4,556	55
14	426	$21,069	$9,243	$1,459	$7,367	$3,814	$8,590	24
15	865	$11,640	$7,823	$9,937	$10,847	$9,727	$9,995	59
16	873	$5,521	$4,661	$10,317	$7,300	$7,379	$7,035	67
17	875N	$5,878	$7,724	$7,779	$6,776	$6,265	$6,884	58
18	875S	$5,452	$5,012	$6,961	$8,351	$6,019	$6,359	67
19	877N	$8,564	$4,811	$7,620	$9,511	$4,944	$7,090	69
20	877S	$5,061	$3,684	$3,803	$6,975	$8,187	$5,542	36
21	883	$2,855	$5,261	$5,274	$5,148	$4,319	$4,572	-
22	887C	$16,034	$23,631	$23,360	$16,405	$20,637	$20,013	153
23	887N	$2,985	$3,264	$4,167	$6,468	$2,791	$3,935	5
24	889	$2,869	$5,254	$4,125	$8,993	$3,710	$4,991	51
25	895N	$5,056	$6,683	$14,655	$3,978	$3,778	$6,830	40
26	897N	$6,557	$5,751	$7,801	$12,017	$8,397	$8,105	43
27	911	$7,298	$6,140	$5,397	$13,105	$8,220	$8,032	69
28	917	$8,134	$4,576	$4,201	$7,015	$10,345	$6,854	66

Riley County provided complete details of all maintenance work that occurred on all county roads from 2010 to 2014, including details on 35 paved routes and 28 gravel routes. Activities on each section differed each year depending on the need of the roadway surface. The AADT of each route was also obtained from the county. Average maintenance costs for paved roads and gravel roads were $33,010 per mile and $7,307 per mile, respectively, from 2010 to 2014 for the given routes.

3.2.4 Washington County

In the year 2013, Washington County had a total of 300 miles of county-maintained roads, consisting of 60 miles (20%) of asphalt roads and 240 miles (80%) of gravel roads. This county does not maintain any concrete or earth roads, but approximately 1,250 miles of roads are maintained by the townships. Washington County provided complete details of all maintenance work that occurred on all county roads from 2012 to 2014, including details on nine paved routes and 44 gravel routes. The county provided available traffic volumes on a few of their county routes for the year 2011, which were carried out by the state. The AADTs of these routes were obtained from traffic volume maps prepared by KDOT. AADT information was available for the years 2011 and 2014.

Maintenance activities are subjectively carried out on roads in Washington County based on the needs of the roadway surface. Roads with poor surface conditions were given higher priority. In addition, maintenance activities performed on all routes were not identical during each year. Details provided by the county showed that a major activity occurred on each paved route almost every alternate year, whereas for gravel routes, maintenance costs did not differ each year. During the early 1990s, many paved sections in the county were converted back to gravel sections due to the high maintenance costs for paved roads. A 2-mile paved road was changed to a gravel road in 1993, and in 1995, the same road was converted back to a chip-sealed (paved) road for approximately $70,000.

According to the 10-year plan proposed by Washington County in 1998 (the most recent 10-year plan was not available), roads with ADT greater than 200 vpd were proposed to be paved. An estimation was made that a mile of paved road costs approximately five times as much to maintain as a mile of gravel road. Fifty-four miles of paved roads were maintained as paved, whereas 6 miles of paved roads were converted back to gravel because of the expense of maintaining those paved roads with relatively less traffic volume. Table 3.11 and Table 3.12 show total maintenance costs for the years 2012 to 2014 for gravel routes and paved routes, respectively.

Table 3.11: Maintenance Details and AADT of Gravel Routes in Washington County

No.	Route	Miles	Total maintenance cost			Maintenance cost/mile				AADT	
			2012	2013	2014	2012	2013	2014	Average	2011	2014
1	RS 1735	2.00	$3,018	$2,081	$5,327	$1,509	$1,041	$2,664	$1,738	42	40
2	RS 1420	4.00	$3,487	$13,091	$8,188	$872	$3,273	$2,047	$2,064	26	48
3	RS 1101	11.00	$52,434	$26,586	$26,090	$4,767	$2,417	$2,372	$3,185	-	-
4	RS 1418	3.00	$4,985	$3,324	$7,115	$1,662	$1,108	$2,372	$1,714	46	60
5	RS 1420	9.00	$17,154	$31,018	$19,487	$1,906	$3,446	$2,165	$2,506	35	67
6	RS 1094	9.00	$25,605	$19,632	$22,860	$2,845	$2,181	$2,540	$2,522	55	55
7	RS 1095	5.00	$35,684	$21,968	$18,697	$7,137	$4,394	$3,739	$5,090	-	-
8	RS 654	8.00	$15,710	$33,399	$14,976	$1,964	$4,175	$1,872	$2,670	41	70
9	RS 1109	3.00	$6,546	$6,504	$7,533	$2,182	$2,168	$2,511	$2,287	43	30
10	RS 656	5.00	$21,210	$13,367	$26,795	$4,242	$2,673	$5,359	$4,091	-	-
11	-	0.50	$760	$0	$2,235	$1,521	$0	$4,470	$1,997	-	-
12	RS 1096	1.50	$17,893	$2,255	$3,477	$11,928	$1,503	$2,318	$5,250	-	-
13	RS 656	7.00	$13,280	$18,767	$32,914	$1,897	$2,681	$4,702	$3,093	66	75
14	RS 1106	3.30	$5,194	$7,627	$16,321	$1,574	$2,311	$4,946	$2,944	90	73
15	RS 1462	4.00	$15,430	$5,701	$14,199	$3,858	$1,425	$3,550	$2,944	25	30
16	RS 658	8.00	$6,825	$88,214	$12,464	$853	$11,027	$1,558	$4,479	-	-
17	RS 655	10.00	$26,263	$48,714	$42,122	$2,626	$4,871	$4,212	$3,903	-	-
18	RS 1098	6.00	$11,709	$18,437	$26,156	$1,952	$3,073	$4,359	$3,128	66	60
19	RS 622	2.00	$2,429	$9,438	$4,598	$1,215	$4,719	$2,299	$2,744	72	55
20	RS 655	2.00	$2,942	$5,862	$18,623	$1,471	$2,931	$9,312	$4,571	-	-
21	RS 622	8.50	$15,193	$25,514	$21,759	$1,787	$3,002	$2,560	$2,450	68	52
22	RS 1418	4.00	$3,817	$9,382	$7,163	$954	$2,346	$1,791	$1,697	43	50
23	RS 334	10.70	$60,062	$80,339	$62,115	$5,613	$7,508	$5,805	$6,309	-	-
24	RS 1106	5.00	$8,513	$8,420	$10,350	$1,703	$1,684	$2,070	$1,819	42	40
25	RS 1102	8.00	$30,184	$29,089	$48,137	$3,773	$3,636	$6,017	$4,475	-	-
26	RS 1833	2.00	$2,695	$2,622	$4,997	$1,348	$1,311	$2,498	$1,719	25	60
27	RS 1493	7.00	$9,106	$26,574	$19,627	$1,301	$3,796	$2,804	$2,634	70	89
28	RS 1102	7.00	$34,434	$28,943	$50,741	$4,919	$4,135	$7,249	$5,434	-	-
29	RS 567	10.50	$3,525	$14,204	$13,419	$336	$1,353	$1,278	$989	-	-
30	RS 1100	10.00	$24,391	$32,429	$30,211	$2,439	$3,243	$3,021	$2,901	-	-
31	RS 1104	2.00	$6,847	$9,512	$10,949	$3,424	$4,756	$5,475	$4,551	-	-
32	RS 578	4.00	$7,666	$6,623	$12,205	$1,917	$1,656	$3,051	$2,208	-	-
33	RS 1108	3.00	$6,813	$5,461	$6,677	$2,271	$1,820	$2,226	$2,106	49	80
34	RS 1105	6.50	$22,736	$27,729	$29,053	$3,498	$4,266	$4,470	$4,078	-	-
35	RS 1420	5.00	$6,007	$9,421	$19,398	$1,201	$1,884	$3,880	$2,322	29	50
36	-	1.50	$7,609	$0	$30,636	$5,072	$0	$20,424	$8,499	-	-
37	RS 578	4.00	$50,002	$8,773	$80,679	$12,500	$2,193	$20,170	$11,621	-	-
38	RS 1103	6.00	$15,822	$12,186	$19,101	$2,637	$2,031	$3,183	$2,617	59	65
39	RS 1494	6.00	$5,101	$19,926	$13,195	$850	$3,321	$2,199	$2,123	30	45
40	-	0.50	$221	$0	$723	$442	$0	$1,446	$629	-	-
41	RS 622	7.00	$7,027	$22,826	$29,618	$1,004	$3,261	$4,231	$2,832	24	45
42	RS 1097	7.00	$16,183	$20,181	$12,726	$2,312	$2,883	$1,818	$2,338	50	62
43	RS 622	3.00	$5,238	$11,940	$35,172	$1,746	$3,980	$11,724	$5,817	-	-
44	RS 1096	7.00	$21,864	$33,710	$28,611	$3,123	$4,816	$4,087	$4,009	-	-

Table 3.12: Maintenance Details and AADT of Paved Routes in Washington County

No.	Route	Miles	Total maintenance cost			Maintenance cost/mile				AADT	
			2012	2013	2014	2012	2013	2014	Average	2011	2014
1	RS 1107	3.00	$24,146	$20,922	$665	$8,049	$6,974	$222	$5,081	265	215
2	RS 654	9.50	$82,307	$2,578	$19,243	$8,664	$271	$2,026	$3,654	196	203
3	RS 125	5.60	$38,171	$54,417	$72,463	$6,816	$9,717	$12,940	$9,824	618	547
4	RS 125	11.00	$27,886	$201,454	$47,173	$2,535	$18,314	$4,288	$8,379	100	162
5	RS 1104	1.90	$30,040	$97,908	$30,303	$15,810	$51,530	$15,949	$27,763	390	465
6	RS 657	11.53	$65,502	$3,829	$73,106	$5,681	$332	$6,341	$4,118	382	390
7	RS 578	2.50	$50,002	$8,773	$80,679	$20,001	$3,509	$32,272	$18,594	115	120
8	RS 1104	2.50	$1,002	$3,239	$142,740	$401	$1,296	$57,096	$19,598	68	95
9	RS 1099	1.50	$444	$789	$23,680	$296	$526	$15,786	$5,536	125	125

The tables show the maintenance cost per mile for 3 years and the average maintenance cost per mile. The tables also show the AADT for the years 2011 and 2014. Average maintenance costs for paved roads and gravel roads from 2012 to 2014 were $11,394 per mile and $3,389 per mile, respectively.

3.2.5 Morris County

In the year 2013, Morris County had a total of 1,121 miles of county-maintained roads, consisting of 99 miles (9%) of asphalt roads, 979 miles (80%) of gravel roads, and 43 miles (4%) of earth roads. This county does not maintain any concrete roads. Morris County provided complete details of all maintenance work on all county roads from 2012 to 2014; maintenance details were provided for every 1-mile section. The county did not provide any traffic volume details. Table 3.13 shows the number of 1-mile sections maintained annually in Morris County from 2012 to 2014.

Table 3.13: Number of 1-Mile Sections Maintained in Morris County (2012–2014)

Years	2012	2013	2014
Number of 1-mile asphalt sections	91	97	93
Number of 1-mile gravel sections	825	843	842
Number of 1-mile soil sections	105	106	108
Total number of 1-mile sections	1,021	1,046	1,043

The average costs of maintenance from 2012 to 2014 were $1,873 per mile for gravel roads and $8,452 per mile for paved roads. Because Morris County maintained details of its 1-

mile sections of roadway, the most common activities that occurred on paved roads and gravel roads and the frequency of those activities could to be identified. The most common activities, corresponding maintenance costs, and maintenance frequencies are shown in Table 3.14, allowing increased understanding of the variation in maintenance activities along roads in Morris County.

Table 3.14: Frequency of Most Common Maintenance Activities and Average Cost per Mile in Morris County

Gravel roads			
No.	**Most common activities carried out on gravel section**	**Frequency of maintenance**	**Average maintenance cost/mile**
1	Mowing	3 times in 3 years	$170
2	Route inspection	2 times in 3 years	$175
3	Shoulder and ditch maintenance	1 time in 3 years	$310
4	Signing and flagging	1 time in 3 years	$300
5	Snow and ice removal	3 times in 3 years	$170
6	Surface gravel	2 times in 3 years	$1,365
7	Tree and brush cutting	1 time in 3 years	$350
8	Route grading	3 times in 3 years	$520
Paved roads			
No.	**Most common activities carried out on paved section**	**Frequency of maintenance**	**Average maintenance cost/mile**
1	Mowing	3 times in 3 years	$190
2	Route inspection	3 times in 3 years	$50
3	Shoulder and ditch maintenance	1 time in 3 years	$120
4	Signing and flagging	2 time in 3 years	$145
5	Snow and ice removal	3 times in 3 years	$300
6	Surface chip seal	2 times in 3 years	$13,900
7	Tree and brush cutting	2 time in 3 years	$440
8	Route grading	2 times in 3 years	$200

3.2.6 Trego County

In the year 2013, Trego County had a total of 1,092 miles of county-maintained roads, consisting of 792 miles (73%) of gravel roads and 300 miles (27%) of earth roads. This county does not maintain any concrete roads or asphalt roads. Trego County provided complete details of all regular maintenance work that occurred on all county roads from 2010 to 2014. Maintenance details were given for every 1-mile section of gravel roads. Table 3.15 shows the number of 1-mile gravel sections annually maintained in the county from 2010 to 2014.

Table 3.15: Number of 1-Mile Gravel Sections Maintained in Trego County (2010–2014)

Year	2010	2011	2012	2013	2014
Number of sections	883	902	903	835	896

A majority of the sections were 1-mile sections and few were less than 1 mile, totaling more than 792 sections. In addition, few sections did not undergo maintenance during a particular year due to major maintenance in the previous year. A few activities were not carried out on any sections in a particular year. In order to maintain uniformity, only sections that were maintained during all 5 years of data were taken into consideration, totaling 811 sections after screening, most of which were 1-mile sections. Roads were subjectively maintained according to road condition and need; consequently, not all activities occurred on all sections. In addition, maintenance activities differed during various years. A few activities occurred on only a few sections during one particular year; therefore, sections with rare activities (activities that occurred on less than 5% of all sections) were discarded to maintain uniformity. Among those sections, the common sections that were maintained during all 5 years were sorted out, leaving 435 sections. Average maintenance costs per mile for maintaining all 435 gravel sections in Trego County from 2010 to 2014 are given in Table 3.16.

Table 3.16: Summary of Maintenance Costs for Trego County (2010–2014)

Years	Total cost of maintenance	Maintenance cost/mile
2010	$395,347	$2,677
2011	$344,455	$2,522
2012	$400,732	$2,451
2013	$51,238	$709
2014	$358,151	$3,076

Limited or basic maintenance work was carried out during the year 2013 according to the available budget and necessity for road maintenance. Average maintenance costs per mile for gravel roads in Trego County were $2,287 per mile from 2010 to 2014 and $2,682 per mile if data from the year 2013 was not considered.

3.3 General Comments

Each county in Kansas was observed to function uniquely. Maintenance decisions made by each county were dependent on current road conditions and county officials' subjective decisions. Personnel changes at county agencies could result in changes in perspective regarding road maintenance. In addition, factors such as topographical changes, weather differences (mainly snowfall variation), percentage of gravel roads, available budget, and availability of materials vary from county to county and recorded cost details related to maintenance activities may differ. For example, consideration of equipment cost in the total maintenance cost may differ between counties depending on whether or not the county owns the maintenance equipment. The method of maintenance activity may also differ depending on the skills and experience of the workers or equipment operators. For example, one worker may perform the blading action on 10 miles of gravel roads in 6 hours, whereas another worker may require 10 hours for the same activity. This variation directly affects the maintenance cost per mile for that particular gravel road.

The county's decision to pave a particular gravel road due to increasing traffic volume may be implemented only if county officials agree. In large counties, political influence significantly impacts the decision-making process, while public involvement is one of the driving factor in small counties. Therefore, a general methodology based on more quantitative factors is needed that can account for all such variation between counties and help each county official make a strong decision regarding pavement surface type. A methodology that considers all variations is developed in the following chapter.

Chapter 4: Methodology

This chapter describes the approaches and methods to calculate cost components, such as life-cycle cost (LCC) and vehicle operating cost (VOC), which are essential in the decision-making process. This chapter formulates and mentions the general equations to carry out the cost calculations that are used for the guidelines developed in Chapter 5. This chapter also includes safety experience on paved surfaces versus gravel surfaces of local rural roads and describes the various ways to achieve safer roadway surfaces by uniformly comparing crash rates and equivalent property damage only (EPDO) crashes. Various factors considered in the final decision of roadway surface-type conversion are also discussed in this chapter.

4.1 Life-Cycle Cost Analysis Approach

LCC is the sum of all the recurring and non-recurring costs over a specified period of a structure. LCC for a roadway section includes initial construction costs and varying maintenance costs over the specific period. Not all maintenance activities on roadway surfaces take place each year. In fact, frequency of maintenance activities differs for each roadway surface based on roadway conditions and traffic volumes. A major maintenance activity such as regravelling may take place only once every 6–7 years depending on the traffic load, but basic maintenance activities that occur on gravel roads, such as blading and resurfacing/reshaping, take place more frequently. Blading removes minor surface defects and corrects the crown to proper slope. Blading is utilized more frequently than many other activities, occurring at least twice each year for low traffic conditions to approximately six to eight times per year for heavy traffic conditions as a result of increased disturbance to the gravel surface. Resurfacing/reshaping, typically carried out once every year, recovers gravel material from the ditch or the shoulder in order to improve drainage and defects throughout the cross section of the road. Spot gravelling, typically also conducted once a year depending on the needs of the surface, corrects isolated defects on roadway surface areas that are less than 1,000 square meters.

Maintenance activities on paved roads include periodic overlays of asphalt, crack sealing, and surface treatments such as chip seal, patching, stripping, and marking. However, not all activities occur during each year. In fact, one particular maintenance practice may affect the need for another maintenance practice. For example, use of chip seal may extend the life of the pavement and increase the intervals between overlay treatments. Crack sealing and patching typically occur once each year or once every 2 years. Chip sealing is done every 3 to 4 years, and overlay is usually applied every 20 years.

In this study, the frequency of maintenance activities was obtained through literature review and detailed Kansas county data. Maintenance costs for each activity differ, however, varying by state and even within counties of one state. Because maintenance practices and maintenance frequencies differ for gravel roads and paved roads, it cannot be compared based on per year cost of maintenance for each roadway type. However, the cost of maintenance for a period of approximately 20 years could be determined (which is considered as a life cycle) and then compared to the maintenance cost of each roadway surface type in order to make a decision about a better alternative.

The equation to calculate total LCC is rather simple if inflation is not taken into consideration (i.e., consistent maintenance cost for all years of period of analysis). However, when considering inflation for the maintenance cost, the equation to calculate the LCC becomes complex. Because costs accrue over several years, the LCC must be calculated to the present value of the dollar by evaluating the present worth value. The present worth evaluation combines all investments and costs and all annual expenses into a single present worth sum that represents the amount of money needed during the current year to satisfy all future costs accrued throughout the analysis period. When comparing alternatives, the one with the lowest present worth is considered to be the most economical option. For this analysis, a default value of 4% interest rate was used, which is generally compatible with government bonds and other government financing plans. The study in South Dakota used an interest rate value of 3.5% (Zimmerman & Wolters, 2004). However, any other interest value can be used as well.

Equation 4.1 was used to calculate the LCC while accounting for inflation. This equation is formulated to be used for any roadway surface type (gravel or paved) for any number of maintenance activities over the roadway surface with varied maintenance cost per mile and varied maintenance frequency for each activity. This equation provides flexibility to calculate the LCC for any road for any local scenario.

$$\mathbf{LCC_{total}} = \sum_{j=1}^{a} \mathbf{C_j} \times \sum_{i=1}^{k} (\mathbf{1 + r})^{\mathbf{f_j \times i}}$$

Where: **Equation 4.1**

LCC_{total} = life-cycle cost for a roadway surface during the analysis period of N years

N = analysis period (years)

a = total number of maintenance activities on the roadway surface

j = each maintenance activity (j = 1, 2, 3,….., a)

k = $|N/f_j|$ = number of times each activity j occurs during LCC analysis period of N years

i = count for each activity j (i = 1, 2, 3,….., k)

C_j = maintenance cost per mile of activity j ($/mile)

f_j = frequency of maintenance of activity j (years)

r = rate of inflation (in decimals [e.g., 4% = 0.04])

Note: The mod (| |) sign for $|N/f_j|$ the number of times a certain activity will occur during a life cycle. For example, |20/3| is 6 and not 6.67.

When $r \neq 0$, Equation 4.1 can be written as:

$$LCC_{total} = \sum_{j=1}^{a} C_j \times \left\{ \frac{(1+r)^{f_j} \times \left[(1+r)^{f_j \times k} - 1\right]}{(1+r)^{f_j} - 1} \right\}$$

Special Case:

When inflation rate is not considered, maintenance costs per mile for each activity remain the same throughout all the years of the analysis period. Therefore, r = 0 and Equation 4.1 becomes:

$$LCC_{total} = \sum_{j=1}^{a} C_j \times \sum_{i=1}^{k} (1+0)^{f_j \times i}$$

$$LCC_{total} = \sum_{j=1}^{a} C_j \times \sum_{i=1}^{k} (1)^{f_j \times i}$$

$$\mathbf{LCC_{total}} = \sum_{j=1}^{a} \mathbf{C_j \times k}$$

Equation 4.2

In order to estimate the present worth of the total amount spent on the life cycle of a roadway surface, the total LCC must be converted to the current year dollar value using the appropriate discount rate. Discount rate is the interest used to determine the present value of future cash value. Equation 4.3 can be used to calculate the present worth value of the LCC of a roadway surface type with inflation.

$$\mathbf{LCC_{PW} = \sum_{j=1}^{a} C_j \times \sum_{i=1}^{k} \left(\frac{1+r}{1+d}\right)^{f_j \times i}}$$

Where: **Equation 4.3**

LCC_{PW} = present worth value of LCC for maintaining a roadway surface during the analysis period of N years

d = discount rate (in decimal)

Special Case:

When the rate of inflation and discount rate are equal (i.e., $r = d$), Equation 4.3 becomes:

$$LCC_{PW} = \sum_{j=1}^{a} C_j \times \sum_{i=1}^{k} \left(\frac{1+r}{1+d}\right)^{f_j \times i}$$

$$= \sum_{j=1}^{a} C_j \times \sum_{i=1}^{k} \left(\frac{1+r}{1+r}\right)^{f_j \times i}$$

$$= \sum_{j=1}^{a} C_j \times \sum_{i=1}^{k} (1)^{f_j \times i}$$

$$\mathbf{LCC_{PW} = \sum_{j=1}^{a} C_j \times k}$$

Equation 4.4

Therefore, the present worth value of the total LCC is equal to the total LCC with no inflation ($r = 0$). In that case, Equation 4.2 and Equation 4.4 become identical.

All previously formulated equations considered only maintenance cost. However, when conversion of a roadway surface occurs, the initial construction cost, also referred to as the conversion cost, should be added to the equations. Therefore, Equations 4.1 to 4.4 become:

$$LCC_{total} = IC_c + \sum_{j=1}^{a} C_j \times \sum_{i=1}^{k} (1+r)^{f_j \times i}$$

Equation 4.5

$$LCC_{total} = IC_c + \sum_{j=1}^{a} C_j \times k$$

Equation 4.6

$$LCC_{PW} = IC_c + \sum_{j=1}^{a} C_j \times \sum_{i=1}^{k} \left(\frac{1+r}{1+d}\right)^{f_j \times i}$$

Equation 4.7

$$LCC_{PW} = IC_c + \sum_{j=1}^{a} C_j \times k$$

Where:

Equation 4.8

IC_c = initial construction cost or conversion cost

4.2 Vehicle Operating Cost

In addition to roadway agency costs, vehicle operating cost (VOC) is important because it varies by vehicle depending on which roadway surface it travels. *Economic Analysis for Highways* states that the VOC on gravel roads is approximately 1.35 times that on paved roads (Winfrey, 1969). Therefore, VOC must be a consideration in the conversion of a roadway surface type or determination of the most economical roadway surface type. VOC components include fuel cost, maintenance cost, tire cost, and depreciation. The book by Winfrey includes tables to calculate the VOC (referred to as running costs by the author) for five classes of vehicles, which represent real traffic flow on roads. As a separate classification for school bus is not mentioned, it can be considered under single unit truck type of vehicle. The five classes of vehicle types, shown in Figure 4.1, are passenger cars, commercial delivery trucks, single-unit trucks, 2-axle tractor semitrailers (2-S2), and 3-axle tractor semitrailers (3-S2).

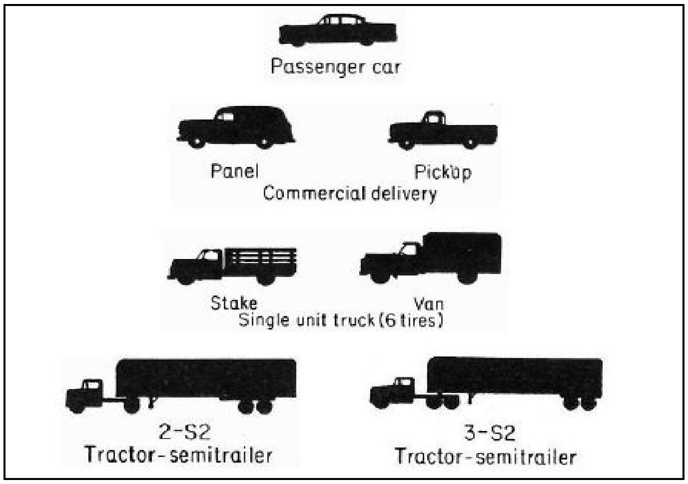


Figure 4.1: Five Classes of Vehicles Used in Calculating VOC
Source: Winfrey (1969)

The detailed tables in *Economic Analysis for Highways* contain empirical values of cost for all five classes of vehicles for various speeds, gradients, and horizontal curves along roadways. All the tables are provided in Appendix D. Running cost values in the tables are for 1,000 VMT and are in dollar values corresponding to the year 1970. Therefore, the running cost of all vehicles for 1 mile for 1 year must be accurately converted to a present dollar value using proper consumer price index (CPI). CPI is a measure of the average change over time in prices paid by urban consumers for consumer goods and services. CPI is the cost of goods or services in any year as compared to the cost of that good or service in the base year (Officer & Williamson, 2015). Since VOC values in *Economic Analysis for Highways* correspond to the year 1970, it was converted to the present year or the year of consideration, such as 2013. The VOC was successfully calculated for any ADT on the roadway with known percentage of vehicles in various classes of vehicles, with roadway gradients, and in the presence of horizontal curves. *Economic Analysis for Highways* also considered roadway surface type when calculating the VOC. The following equations were used to compute the VOC for any combination of vehicles on any type of roadway surface (paved or gravel) with any gradient and horizontal curve. The VOC of all vehicles for a known ADT on a paved road for a particular speed *s* for 1,000 VMT is calculated as:

$$VOC_P = ADT \times \sum_{i=1}^{5} p_i \times [C_{gi} + C_{hi}]$$

Where: **Equation 4.9**

VOC_P = vehicle operating cost of given vehicles on a paved road

ADT = average daily traffic on the road under consideration

i = class of vehicle type (i = 1 to 5)

p_i = percentage of each vehicle class i

C_{gi} = running cost of vehicle class i on any gradient g for a given speed s

C_{hi} = running cost of vehicle class i on any horizontal curve h for given speed s

The VOC of all vehicles for a known ADT on a gravel road for particular speed *s* for 1,000 VMT is calculated as shown in Equation 4.10.

$$VOC_G = ADT \times \sum_{i=1}^{5} p_i \times [C_{gi} + C_{hi}] \times CF_g$$

Where: **Equation 4.10**

VOC_G = vehicle operating cost of given vehicles on a gravel road

CF_g = conversion factor to obtain the running cost on a gravel road for given speed *s*

The VOC of all vehicles for a known ADT on a paved road for a particular speed *s* for 1 VMT for 1 year is calculated as shown in Equation 4.11.

$$VOC_P = \frac{ADT \times 365}{1000} \times \sum_{i=1}^{5} p_i \times [C_{gi} + C_{hi}]$$

Equation 4.11

The VOC of all vehicles for a known ADT on a gravel road for a particular speed *s* for 1 VMT for 1 year is calculated as shown in Equation 4.12.

$$VOC_G = \frac{ADT \times 365}{1000} \times \sum_{i=1}^{5} p_i \times [C_{gi} + C_{hi}] \times CF_g$$

Equation 4.12

The VOC for present dollar value can be calculated by multiplying the VOC equations with the correct transportation CPI value for the given year of consideration according to the Bureau of Labor Statistics using the CPI Inflation Calculator (U.S. Bureau of Labor Statistics, n.d.). Equation 4.13 and Equation 4.14 show the VOC for present dollar value using CPI for paved road and gravel road, respectively.

$$VOC_P = \frac{CPI \times ADT \times 365}{1000} \times \sum_{i=1}^{5} p_i \times \left[C_{gi} + C_{hi}\right]$$

Equation 4.13

$$VOC_G = \frac{CPI \times ADT \times 365}{1000} \times \sum_{i=1}^{5} p_i \times \left[C_{gi} + C_{hi}\right] \times CF_g$$

Where:

Equation 4.14

CPI = transportation consumer price index to convert the 1970-dollar value to present year dollar value

CPI value is 6.004 to convert the 1970-dollar value to 2013-dollar value (U.S. Bureau of Labor Statistics, n.d.). The year 2013 is considered in this study to maintain uniformity in costs because most available details on agency cost are averaged for the year 2013.

Various combinations of percentages of vehicle classes (p_i), vehicle speeds (s), gradients (g), and horizontal curves (h) could exist in a real-world scenario. Therefore, a computer-based program was designed using Visual Studio 2015 in order to obtain the running cost of any number of vehicles. The program calculates the running cost value for any given speed, gradient, and horizontal curve from specific tables according to vehicle class. After obtaining the running costs, various cost components are precisely added and the VOC is given as an output. Inputs for calculating the VOC on a roadway surface for given traffic are type of roadway surface (paved or gravel), ADT on a given roadway, traffic distribution by vehicle class (% of vehicle types), speed of all vehicles (generally the posted speed limit for a given roadway), gradient of the road, if any (default = 0), and horizontal curve of the roadway, if any (default = 0).

Roadway surface type is usually known, and traffic volume can be approximately assumed for the current location if it is not measured or known. Distribution of vehicle types can be obtained at least approximately, and the speed of all vehicles can be assumed as the posted speed limit of the roadway. If a variable such as gradient of the road or horizontal curvature is difficult to know, then it is assumed zero for simplicity.

The VOC calculated using tables provided in *Economic Analysis for Highways* gives the running cost of a vehicle on a roadway surface (Winfrey, 1969). It does not consider ownerships costs such as insurance costs, registration, and taxes because ownership cost is constant and does not have any significance depending on roadway surface type (i.e., ownership cost is identical irrespective of vehicle traveling on a paved road or a gravel road).

Using the tables provided in Appendix D and properly adjusting the cost with the appropriate CPI index for the year 2013, the VOC for 1 mile of travel by each of the five vehicle classes was calculated as shown in Table 4.1.

Table 4.1: VOC per Mile on Paved and Gravel Surfaces for Five Vehicle Classes

No.	Vehicle Class	On paved surface	On gravel surface
1	Passenger car	$0.21	$0.29
2	Commercial delivery truck	$0.24	$0.33
3	Single-unit truck	$0.41	$0.59
4	2-axle tractor semitrailer (2-S2)	$0.63	$0.91
5	3-axle tractor semitrailer (3-S2)	$0.60	$0.90

NOTE: Values were computed for an average speed of 40 mph, zero gradient, and zero horizontal curve.

The American Automobile Association (AAA) estimated the average operating cost per mile for a sedan (passenger car) on a paved surface to be 20.42 cents and 22.39 cents for a minivan (commercial delivery truck; AAA, 2013). Therefore, the proposed method to calculate the VOC using the literature (Winfrey, 1969) and proper CPI value is nearly identical and can be considered.

4.3 Safety Experience

As shown in the literature, many studies have suggested that safety experience on paved roads is better than that on gravel roads. When a roadway surface conversion is imminent, safety concerns must be addressed. A previous study of crash severity on gravel roads in Kansas showed that crash severity is higher for crashes on gravel roads (Liu & Dissanayake, 2009). The study determined that speed limit is one of the major factors that increase crash severity on gravel roads. Determining number of crashes on paved roads and gravel roads provides an understanding of safer roadway surface type. The total number of crashes is not an ideal way to compare safety experience between the roadway surfaces. Because VMT is typically greater on paved roads than gravel roads, the number of crashes is expected to be higher on paved roads compared to gravel roads. Therefore, total VMT along a section of *m* miles for *n* years can be written as:

$$\textbf{Total VMT for } n \textbf{ years} = n \times 365 \times \text{AADT} \times m \qquad \textbf{Equation 4.15}$$

Where:

VMT = vehicle miles traveled

n = number of years

AADT = average annual daily traffic (vpd)

m = mileage of the roadway surface (in miles)

Thus, determining crash rates increases understanding of the safety of a roadway surface type. Crash rate is the observed number of crashes along a roadway section per VMT along that section for given number of years of analysis. Crash rate can be computed as:

$$\text{CR} = \frac{\text{Number of crashes during 'n' years} \times 10^6}{\text{total VMT}}$$

Where: **Equation 4.16**

CR = crash rate in number of crashes per million VMT

n = number of years of analysis

In addition, investigating the different types of crash severity as property damage only (PDO) crash, injury crash, and fatal crash provides additional insight into the safety issues since injury crashes and fatal crashes are more severe than PDO crashes and the costs of fatal crashes and injury crashes are significantly higher than PDO crashes. Therefore, number of EPDO crashes were computed in order to make reasonable comparison considering various crash severities. When calculating EPDO crashes, a weight is assigned to each fatal or injury crash to represent overall severity.

$$\textbf{EPDO} = \begin{matrix}\textbf{number of}\\ \textbf{PDO crashes}\end{matrix} + \left(w_1 \times \begin{matrix}\textbf{number of}\\ \textbf{injury crashes}\end{matrix}\right) + \left(w_2 \times \begin{matrix}\textbf{number of}\\ \textbf{fatal crashes}\end{matrix}\right)$$

Equation 4.17

Where:

W_1 = weight factor to convert injury crashes to PDO crashes

$$= \frac{\text{Average injury crash cost}}{\text{Average PDO crash cost}}$$

W_2 = weight factor to convert fatal crashes to PDO crashes

$$= \frac{\text{Average fatal crash cost}}{\text{Average PDO crash cost}}$$

For Kansas, $W_1 = W_2 = 15$ (Dissanayake & Esfandabadi, 2015). Thus, Equation 4.17 becomes:

$$\textbf{EPDO} = \begin{matrix}\textbf{number of}\\ \textbf{PDO crashes}\end{matrix} + 15\left(\begin{matrix}\textbf{number of}\\ \textbf{injury crashes}\end{matrix} + \begin{matrix}\textbf{number of}\\ \textbf{fatal crashes}\end{matrix}\right)$$

Equation 4.18

Comparing observed EPDO crashes and EPDO crash rates is expected to reveal the safer roadway surface type.

4.4 Multi-Criteria Assessment

Because various factors contribute to the roadway surface decision, a standard method must be developed that considers all factors with their correct respective importance. The important factors were determined via the Kansas county survey, and the weights to those factors were calculated using survey responses. In the following sections, important factors for consideration regarding roadway surface conversion are explained, including how each factor favors a particular roadway surface type.

4.4.1 Agency Cost

Minimization of agency costs is a primary goal for every county. Agency costs include construction or conversion costs and maintenance costs. As mentioned in Section 4.1, agency cost is calculated using the LCC approach. The value of agency cost can be obtained using relevant equations from Equation 4.1 to 4.8. In general, the maintenance cost per mile for a gravel road is higher than the maintenance cost per mile for a paved road. Because various maintenance activities are carried out over the life-cycle period, the LCCs for a gravel road and a paved road should be compared. Adjusting the LCC to the present worth value for the year of consideration also illuminates which alternative is most economical. When considering the conversion of gravel road to paved road, initial construction costs must be included with maintenance costs in order to calculate the LCC.

4.4.2 Vehicle Operating Cost

The VOC can be calculated using the methodology explained in Section 4.2 and using Equations 4.13 and 4.14. Each county must also consider how to minimize VOC in order to satisfy the public. VOC on a gravel road is higher than on a paved road because a vehicle has to overcome friction on gravel roads, leading to increased wear and tear of tires and increased oil consumption and subsequent increased maintenance costs for the vehicle.

4.4.3 Average Annual Daily Traffic (AADT)

AADT is another important consideration for many agencies. Roads with high AADT often are of high maintenance priority for many agencies. In addition, it seems more economical to have gravel roads for low AADT and paved roads for high AADT.

4.4.4 Safety

Safety is an important issue that must be addressed. Literature study indicates that paved roads are safer than gravel roads (Zegeer et al., 1994). Injury crash rates and fatal crash rates are higher on gravel roads than paved roads (Caldwell & Wilson, 1999).

4.4.5 Purpose of Road Usage

The purpose for which the road is mainly used also plays an important role in determining the roadway surface. School routes should preferably be paved because paved roads have been proven to be safer than gravel roads. A route for heavy vehicles is also preferred to be paved, while routes that connect farms to markets can remain gravel because those routes primarily accommodate only tractors and vehicles carrying agricultural products. In addition, when a farm-to-market route remains as a gravel road, the farmers or local people can maintain the road temporarily, which is impossible if the road is paved and requires maintenance from the agency or the county.

4.4.6 Public Preference

Public preference should also be considered when determining a road surface type. The public generally prefers paved roads because paved roads psychologically promote a feeling of safety. In addition, paved roads are smoother, allow higher operating speeds, and generate limited or no dust.

4.4.7 Other Factors

Other factors that may be considered when determining road surface type include material availability, present and future development in the area, and housing density. If the material required for maintenance of a gravel road is locally available or the gravel quarry site is close to the road to be maintained, then the road can continue as a gravel road due to minimal transportation costs. If that road segment has a very high volume of traffic, then the economical decision may be to have the road paved, depending on what the agency decides. Roads with low housing density can have a gravel road or paved road. Paved roads often lead to good development in the surrounding area with opportunity for new businesses.

4.5 Multi-Factor Criteria Development

For low volume local roads in rural areas, all factors previously discussed assist in the decision of whether to have a gravel road or a paved road surface. When considering all seven factors individually, some factors favor gravel-surfaced roads while some others favor paved roads. This section illustrates respective weightage to each factor depending on the importance in order to determine the better roadway surface type.

4.5.1 Weighting Factor

Each of the seven factors mentioned in Section 4.4 is assigned a weight to represent the importance of the factor relative to the other factors. For example, if all the factors are considered equally important, then they should be assigned equal weights. The weights can also be determined in other ways. The weighting factor for this study was calculated based on the survey responses that were gathered from Kansas counties. The weight assigned to all the factors must sum up to 1.0; factors with higher weight reflect increased importance. The weights can be changed depending on local variation and priorities.

4.5.2 Scaled Value

Scaling is used to express all factors in comparable units. A scale of 0 to 100 is typically used, with 0 being not acceptable and 100 being highly acceptable. When considering the costs, the alternative with the minimum or lower value is preferred and therefore has a value of 100. The scaled value for the alternative is calculated based on the percent difference between the two alternatives (Figueroa et al., 2013), shown in Equation 4.19 as:

$$S_a = 100 - 100 \times \left[\frac{C_{high} - C_{low}}{\left(\frac{C_{high} + C_{low}}{2} \right)} \right] \qquad \textbf{Equation 4.19}$$

Where:

S_a = scaled value for the alternative

C_{high} = alternative with higher cost value (not preferred)

C_{low} = alternative with lower cost value (preferred)

If the difference between the costs of two alternatives is less, then the scaled values are close. If the difference between the costs is high, an increased difference exists between the scaled values. Equation 4.19 is used to find the scaled values for paved roads and gravel roads while considering agency cost and VOC. The same formula can be used to compare EPDO crash rates instead of comparing the costs to obtain the scaled value.

For factors in which no direct comparison exists between costs or crash rates, scaled values are calculated differently, as explained in Chapter 5.

4.5.3 Total Score

Calculation of the total score combines weighing factors and scaled values into a single score to determine the best alternative for selection. The total score is the sum of the product of the weighing factors (W_i) and scaled values (S_i) for all factors. It can be mathematically written as shown in Equation 4.20.

$$\mathbf{Score_{total}} = \sum_{i=1}^{7} \mathbf{W_i \times S_i}$$

Equation 4.20

The alternative with the highest total score is presumed to be the better alternative, whether it be gravel or paved surface. If any factor is considered to be not important according to local agencies, they can omit that factor and redistribute the weights to sum it up to 1.0.

Chapter 5: Guideline Development

This chapter explains the development of general guidelines for determining a suitable roadway surface type for any local situation and given set of conditions. The latter part of the chapter explains another approach that considers cost versus traffic volume to determine the break-even point of traffic volume while considering the conversion from gravel surface to paved surface.

5.1 General Guideline Development and Example

All the factors discussed in Section 4.4 aid in the decision of whether to utilize a gravel road or a paved road surface. While considering all those seven factors individually, some factors favored gravel-surfaced roads and some favored paved surfaced roads. This section compares each factor with its respective weightage and develops a procedure that determines a more suitable roadway surface type. This section also explains use of the proposed methodology of multi-criteria assessment in guideline development by providing an example in order to increase understanding of how scaled values for each factor are calculated and used to compute the final score.

5.1.1 Weighting Factor

The importance of considering the weightage factor was explained in Section 4.5.1. Because not all of the seven factors have equal importance, determination must be made as to which factors are more important, and then weights must be assigned to each factor. The weightage for each factor was calculated using important factors from Table 3.2 based on survey responses from Kansas counties and from the literature. Table 5.1 shows the weightage of each of the seven factors that help determine roadway surface type. Weights do not need to be equal to the ones shown in Table 5.1, and can be changed depending on local priorities, if necessary.

Table 5.1: Weightage of Seven Factors for Deciding Roadway Surface Type

No.	Factors	Weight
1	Agency cost	0.25
2	Safety	0.20
3	VOC	0.15
4	Traffic volume or AADT	0.15
5	Purpose of road usage	0.15
6	Public preference	0.05
7	Others	0.05
	Total	1.00

5.1.2 Scaled Value

Scaled values for paved roads and gravel roads for all factors were calculated using the proposed methodology and survey responses.

5.1.2.1 Agency Cost

Agency cost includes maintenance costs and initial construction or conversion costs. A comparison of agency cost for gravel roads and paved roads was done using the LCC analysis approach. Agency cost comparison is categorized into the following two cases.

Case 1: Considering only maintenance costs for gravel and paved surface types:

This type of comparison is done using any equation from Equation 4.1 to Equation 4.4 depending on consideration of rate of inflation and present worth evaluation. The roadway surface type with lower LCC is preferred. If rate of inflation r is considered and present worth evaluation is performed considering the discount rate d, and if

$$\left(\sum_{j=1}^{a} C_j \times \sum_{i=1}^{k} \left(\frac{1+r}{1+d}\right)^{f_j \times i}\right) \text{for gravel road} > \left(\sum_{j=1}^{a} C_j \times \sum_{i=1}^{k} \left(\frac{1+r}{1+d}\right)^{f_j \times i}\right) \text{for paved road,}$$

then a paved-surface road is preferred and vice versa. The scaled value of the preferred surface type is taken as 100 and that for the other surface type is calculated using Equation 4.19.

Details of gravel roads and paved roads of Morris County were used as an example to compare only maintenance costs. Morris County was selected because officials provided detailed information for paved sections and gravel sections with maintenance cost per mile and maintenance frequencies for most common activities. Table 3.14 contains details about Morris County which are summarized in Table 5.2 to be directly used in LCC analysis equations. For calculating the present worth for paved and gravel roads and assuming that the rate of interest and inflation rate are equal and that the analysis period is 20 years, Equation 4.4 could be used to compute the LCC, as shown in the following section.

Table 5.2: Maintenance Details for Gravel Roads in Morris County

Gravel Road Details		
Activities	**Frequency of maintenance**	**Maintenance cost/mile**
Mowing	f_1 = 1 year	C_1 = $170/mile
Route inspection	f_2 = 2 years	C_2 = $175/mile
Shoulder and ditch maintenance	f_3 = 3 years	C_3 = $315/mile
Signing and flagging	f_4 = 3 years	C_4 = $300/mile
Snow and ice removal	f_5 = 1 year	C_5 = $170/mile
Surface gravel	f_6 = 2 years	C_6 = $1,365/mile
Tree and brush cutting	f_7 = 3 years	C_7 = $350/mile
Route grading	f_8 = 1 year	C_8 = $520/mile
Regravelling	f_9 = 4 years	C_9 = $12,000/mile
Paved Road Details		
Activities	**Frequency of maintenance**	**Maintenance cost/mile**
Mowing	f_1 = 1 year	C_1 = $190/mile
Route grading	f_2 = 2 years	C_2 = $200/mile
Route inspection	f_3 = 1 year	C_3 = $50/mile
Shoulder and ditch maintenance	f_4 = 3 years	C_4 = $120/mile
Signing and flagging	f_5 = 2 years	C_5 = $145/mile
Snow and ice removal	f_6 = 1 year	C_6 = $300/mile
Surface chip seal	f_7 = 3 years	C_7= $13,900/mile
Tree and brush cutting	f_8 = 2 years	C_8 = $440/mile

For gravel roads,

$$LCC_{PW} = \sum_{j=1}^{a} C_j * k \qquad \begin{cases} k = |N/f_j| \\ N = 20,\ a = 9 \\ C_j \text{ and } f_j \text{ are given in Table 5.12} \end{cases}$$

$$LCC_{PW} = \sum_{j=1}^{a} C_j * k = \sum_{j=1}^{a} C_j * \left|\frac{N}{f_j}\right|$$

$$LCC_{PW} = C_1 * \left|\frac{N}{f_1}\right| + C_2 * \left|\frac{N}{f_2}\right| + C_3 * \left|\frac{N}{f_3}\right| + C_4 * \left|\frac{N}{f_4}\right| + C_5 * \left|\frac{N}{f_5}\right| + C_6 * \left|\frac{N}{f_6}\right| + C_7 * \left|\frac{N}{f_7}\right| + C_8 * \left|\frac{N}{f_8}\right| + C_9 * \left|\frac{N}{f_9}\right|$$

$$LCC_{PW} = 170 * \left|\frac{20}{1}\right| + 175 * \left|\frac{20}{2}\right| + 315 * \left|\frac{20}{3}\right| + 300 * \left|\frac{20}{3}\right| + 170 * \left|\frac{20}{1}\right| + 1365 * \left|\frac{20}{2}\right| + 350 * \left|\frac{20}{3}\right| + 520 * \left|\frac{20}{1}\right| + 12000 * \left|\frac{20}{4}\right|$$

$$LCC_{PW} = \$98{,}390$$

For paved roads,

$$LCC_{PW} = \sum_{j=1}^{a} C_j * k \qquad \begin{cases} k = |N/f_j| \\ N = 20,\ a = 8 \\ C_j \text{ and } f_j \text{ are given in Table 5.12} \end{cases}$$

$$LCC_{PW} = \sum_{j=1}^{a} C_j * k = \sum_{j=1}^{a} C_j * \left|\frac{N}{f_j}\right|$$

$$LCC_{PW} = C_1 * \left|\frac{N}{f_1}\right| + C_2 * \left|\frac{N}{f_2}\right| + C_3 * \left|\frac{N}{f_3}\right| + C_4 * \left|\frac{N}{f_4}\right| + C_5 * \left|\frac{N}{f_5}\right| + C_6 * \left|\frac{N}{f_6}\right| + C_7 * \left|\frac{N}{f_7}\right| + C_8 * \left|\frac{N}{f_8}\right|$$

$$LCC_{PW} = 190 * \left|\frac{20}{1}\right| + 200 * \left|\frac{20}{2}\right| + 50 * \left|\frac{20}{1}\right| + 120 * \left|\frac{20}{3}\right| + 145 * \left|\frac{20}{2}\right| + 300 * \left|\frac{20}{1}\right| + 13900 * \left|\frac{20}{3}\right| + 440 * \left|\frac{20}{2}\right|$$

$$LCC_{PW} = \$102{,}770$$

While considering the costs, the road surface alternative with the lower cost is preferred, and thus it has the value of 100. In this example, the present worth of LCC for a gravel road is less than the present worth of a paved road, which is the preferred option. Thus, the scaled value for a gravel road becomes 100.

The scaled value for a paved road is calculated based on the percent difference between the two alternatives using Equation 4.19.

$$S_a = 100 - 100 \left[\frac{C_{high} - C_{low}}{\left(\frac{C_{high} + C_{low}}{2} \right)} \right] = 100 - 100 \left[\frac{102770 - 98390}{\left(\frac{102770 + 98390}{2} \right)} \right] = 95.65$$

Thus, the scaled value for gravel road is 57.45. Scaled values for a gravel road and a paved road were used while considering all factors together using multi-factor criteria development.

Maintenance costs and maintenance frequencies are not necessarily identical in every county; the rate of interest and discount rate can also differ and the analysis period may differ. This section uses only one scenario to demonstrate the proposed methodology. To account for local variation and preference, a computer-based program was devised for the methodology.

Case 2: Consider maintenance plus conversion costs for gravel and paved surface types.

Initial construction costs of a paved road compared to a gravel road varies depending upon thickness of the HMA used as the paved roadway surface. In McPherson County, the cost of converting 1.3 miles of gravel road to paved road was $828,500 in 2010; thus, the conversion cost was $637,300 per mile ($680,850 per mile in 2013-dollar value). In Lyon County, the cost of converting 3 miles of gravel road to paved road in the year 2007 was $1,091,025; thus, the conversion cost per mile was $363,675 per mile ($408,600 per mile in 2013-dollar value). Roadway surface conversion also can occur from paved to gravel roadway surface. In Washington County, 2 miles of paved road were converted back to gravel in 1995 for a total cost of $70,000; thus, the conversion cost was $35,000 per mile ($53,500 per mile in 2013-dollar value).

When initial construction or conversion costs are included with the maintenance cost, then any equation from Equation 4.5 to Equation 4.8 should be used, depending on conditions, to calculate the LCC and follow the previously described steps to calculate the scaled values.

5.1.2.2 Safety

The literature suggests that safety on paved roads is better than on gravel roads. To verify, safety analysis was carried out for local rural roads in Kansas. However, a safety study is difficult because no proper resource is available to determine the crash rate on rural local roads with low volumes.

The Kansas Crash Analysis and Reporting System (KCARS) database contains records of all reportable crashes in Kansas. After obtaining the KCARS database from KDOT, crashes on local rural roads in Kansas were investigated. Crash details of local roads in Kansas were filtered by observing the *NONSTATE_FUNCTION_CLASS* field from the *Accidents* Table. If the NONSTATE_FUNCTION_CLASS = 07, then it is a local road crash. The *UAB* field in the *Accidents* table from the KCARS database indicates if the crash was urban or rural. If UAB = 999, then it was a rural crash, and if UAB ranges from 001 to 888, then it was an urban crash. All crashes on local rural roads in Kansas were screened using proper queries. The data used for this study was from the years 2010 to 2014. All local rural crashes on various roadway surfaces during those 5 years are shown in Figure 5.1.

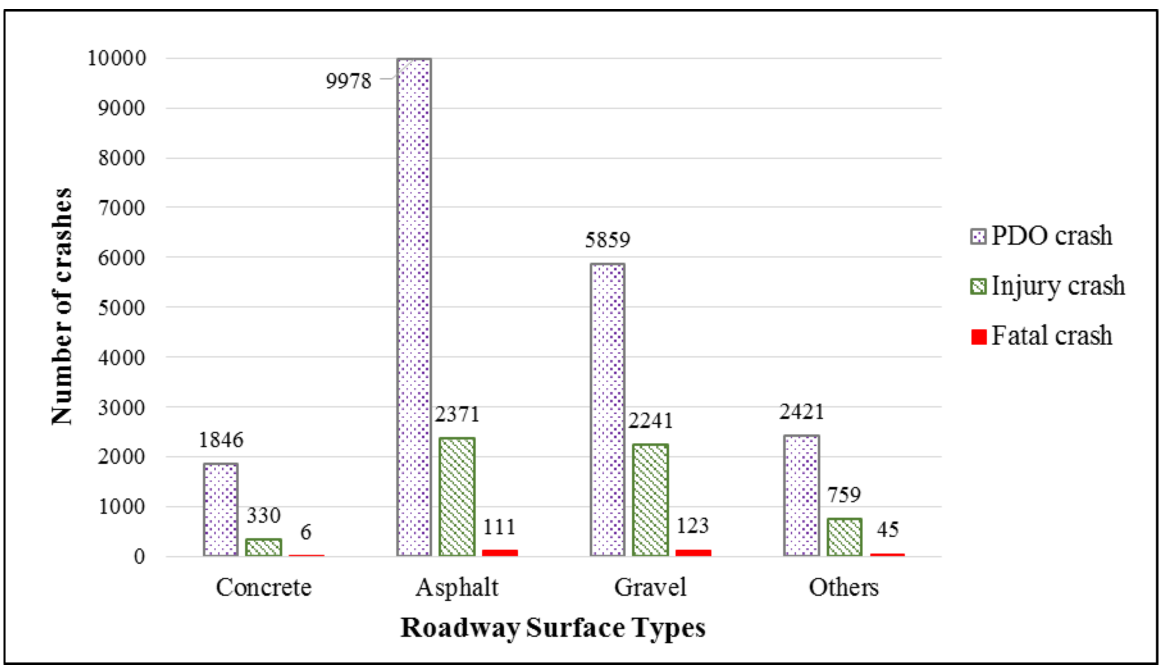


Figure 5.1: Number of Crashes on Rural Roads in Kansas (2010–2014)

For the purpose of this study, only crashes on asphalt roads (paved) and gravel roads were considered. Results showed that the total number of crashes on asphalt roads was higher than the number of crashes on gravel roads. However, the number of fatal crashes on local rural gravel roads was higher than the number of fatal crashes on asphalt roads. In addition, the VMT on asphalt roads was much higher than on paved roads. Therefore, in order to identify the safest roadway surface type, crash rates (based on VMT) on asphalt roads and gravel roads were compared. Traffic volume details on gravel roads and paved roads and mileage of the roadway surface type were necessary to determine the VMT. The mileage of gravel roads and paved roads was available in the *Summary of County Engineers' Annual Reports* (KDOT, 2013), but traffic volume details on paved and gravel roads were not available. Determination of traffic volume details for various counties was difficult; therefore, in order to obtain an estimation of traffic volume, the survey of Kansas counties provided a range of traffic volume on paved roads and gravel roads by county. Out of the 77 counties that replied to the survey questionnaire, 61 counties (79%) provided a range of traffic volumes on paved roads and gravel roads. However, out of the 61 counties, only 58 counties provided traffic volumes for both paved roads and gravel roads. In addition, two counties did not maintain any paved roads. Thus, crash details of only 56 counties were computed. The VMT on the roadway surface for 5 years was calculated using mileage of each surface type in each county and traffic volume on that surface. The VMT during n years was calculated using Equation 4.15. In Appendix E, Table E.1 shows paved and gravel AADT and mileage for the 56 counties considered for safety analysis and VMT calculated using Equation 4.15.

Crash details for the 56 counties for 5 years (2010–2014) on paved roads and gravel roads are shown in Appendix E, Table E.2. Details were obtained from the KCARS database provided by KDOT. The table shows that the number of PDO crashes and injury crashes were greater on paved roads compared to gravel roads, but the number of fatal crashes was higher on gravel roads, totaling 76 fatal crashes compared to 55 fatal crashes on paved roads.

Crash rates were calculated using Equation 4.16 and in reference to Table E.1 and Table E.2 from Appendix E. Crash rates for crashes on paved roads and gravel roads are shown in Appendix E, Table E.3. The average crash rate for PDO crashes was higher on paved roads as compared to gravel roads, but average crash rates for injury and fatal crashes were higher for gravel roads compared to paved roads. Overall, the average total crash rate was higher on gravel roads, with 303.34 crashes per hundred million VMT compared to 291.74 crashes per hundred million VMT on paved roads. However, crash costs for injury crashes and fatal crashes were considerably higher compared to only PDO crashes. Therefore, the recommendation was made to compute the EPDO in order to make reasonable comparison of crash costs. When calculating EPDO crashes, a weight was assigned to each fatal or injury crash to represent overall severity. Using Equation 4.18, the number of EPDO crashes, and using Equation 4.16, EPDO crash rates for paved roads and gravel roads were calculated for Kansas, as shown in Appendix E, Table E.4. The average number of EPDO crashes was higher on paved roads, with 493 total EPDO crashes compared to 409 total EPDO crashes on gravel roads during the 5 years of the analysis period. In contrast, the average EPDO crash rate was higher on gravel roads, with 1,427.22 crashes per hundred million VMT as compared to only 851.57 crashes per hundred million VMT on paved roads.

Thus, the safety analysis on local rural roads in Kansas showed that paved roads were safer than gravel roads, with only 851.57 EPDO crashes per hundred million VMT compared to 1,427.22 EPDO crashes per hundred million VMT on gravel roads. In Section 4.5.1, Morris County information was used as an example for calculating scaled values on paved roads and gravel roads considering agency cost. In order to maintain uniformity, safety information of Morris County was used as an example to demonstrate the use of safety effects in determining the surface type. For Morris County, the EPDO crash rate was greater on paved roads than gravel roads, with 245.38 EPDO crashes per hundred million VMT compared to 110.34 EPDO crashes per hundred million VMT on gravel roads (Table E.4 from Appendix E). Because the gravel road had a lower EPDO crash rate, it was the preferred roadway surface, with a scaled value of 100. The scaled value for a paved road was calculated using Equation 4.19 as:

$$S_a = 100 - 100\left[\frac{C_{high} - C_{low}}{\left(\frac{C_{high} + C_{low}}{2}\right)}\right] = 100 - 100\left[\frac{245.38 - 110.34}{\left(\frac{245.38 + 110.34}{2}\right)}\right] = 24.08$$

Scaled values for safety can be determined for any county considering any number of sections with crash data for a few previous years and other required details such as VMT. Safer roadway surface type can be determined using a similar approach to calculate and compare EPDO crash rates.

5.1.2.3 Vehicle Operating Cost

The VOC for vehicles on paved roads and gravel roads can be calculated using Equation 4.13 and Equation 4.14, respectively. After calculating the VOC per mile for 1 year, scaled values can be determined. Because the VOC for a vehicle on a paved road was shown to be less than on a gravel road, the scaled value for paved road would be always 100. The scaled value for a gravel road can be calculated using Equation 4.19.

For example, if traffic volume was 175 vpd with 90% passenger cars and 10% trucks with speed of 40 mph and the roadway had no gradient or horizontal curvature, then using Equation 4.13 and Equation 4.14, the VOC per mile for 1 year for all 175 vehicles on paved surface and gravel surface would be \$15,920 and \$22,700, respectively. The scaled value for a paved road is 100. The scaled value for a gravel road can be calculated using Equation 4.19 as:

$$S_a = 100 - 100\left[\frac{C_{high} - C_{low}}{\left(\frac{C_{high} + C_{low}}{2}\right)}\right] = 100 - 100\left[\frac{22700 - 15920}{\left(\frac{22700 + 15920}{2}\right)}\right] = 65.$$

5.1.2.4 AADT

Scaled values for traffic volumes can be obtained by knowing the percentage of miles of roads with specific range of traffic volume. Roads with traffic volume in the range of 50 each (i.e., 0–49, 50–99, 100–149, 150–199, etc.) are considered, and then the percentage of gravel roads and paved roads within each range is determined, which can be obtained by traffic volume counts in the county or by best judgments from county engineers or road supervisors. However, the AADT data is difficult to obtain from all counties due to limited funds in small counties with limited resources to conduct traffic related studies. In such cases, logical values that could be used are shown in Table 5.3.

Table 5.3: Logical Scaled Values for Paved and Gravel Roads for AADT Ranges

AADT (vpd)	0–49	50–99	100–149	150–199	200–249	250–299	300–349	350–399	400 +
Scaled value for gravel	90	80	70	60	50	40	30	20	10
Scaled value for paved	10	20	30	40	50	60	70	80	90

Survey responses from the counties recorded the approximate range of traffic volume on gravel roads and paved roads. A total of 77 out of 105 Kansas counties replied to the survey, out of which 61 counties gave the approximate range of vpd on their gravel and paved roads. Using the average of the range given by the counties, scaled values for gravel and paved roads were calculated, as shown in Table 5.4.

Table 5.4: Survey Results of Scaled Values for Paved and Gravel Roads for AADT Ranges

AADT range (vpd)		0–49	50–99	100–149	150–199	200–249	250–299	300 +
No. of counties having avg. AADT within given range	On gravel road	5	18	21	6	4	4	3
	On paved road	1	6	9	3	2	4	36
Scaled value for gravel		83	75	70	67	67	50	8
Scaled value for paved		17	25	30	33	33	50	92

The logical approach would be: roads with low AADT would have higher scaled values for gravel roads, gradually decreasing with increased AADT. For the earlier assumption of 175 vpd on a roadway surface, the scaled value depending on AADT for a paved road and a gravel road would be 40 and 60, respectively, according to Table 5.3.

5.1.2.5 Purpose of Road Usage

The purpose of road usage factor also contributes to decision-making when selecting the road surface type. Scaled values according to survey responses are given in Table 5.5.

Table 5.5: Scaled Values for Paved and Gravel Roads Depending on Road Usage

Road usage	Scaled value for paved	Scaled value for gravel
Heavy vehicle route	84	16
School route	74	26
Retail and commercial route	73	27
Farm-to-market route	68	32
Government facility route	60	40
Parks and community route	59	41
Residential mail route	58	42
Church route	51	49

These scaled values can be changed according to the best judgments of the county engineer or road supervisor to better fit their local scenario. If the argument is made that a farm-to-market route is better left as gravel, then the scaled values can be adjusted accordingly. For example, assuming the route under consideration is a school route, the scaled values for paved and gravel would be 74 and 26, respectively.

5.1.2.6 Public Preference

The survey questionnaire did not include public preference, but a few comments from the survey revealed some conversions of gravel roads to paved roads due to public demand. Moreover, some counties received many requests from the public to convert gravel roads to paved roads, but the county could not oblige due to budget constraints. Scaled values for public preference are given in Table 5.6.

Table 5.6: Scaled Values for Paved and Gravel Road Depending on Public Preference

Public preferences	Scaled values for paved	Scaled values for gravel
Paved roads with high level of maintenance	100	0
Paved roads with low level of maintenance	50	50
Gravel roads with high level of maintenance	50	50
Gravel roads with low level of maintenance	0	100

Assuming that the public prefers a paved road with a low level of maintenance, the scaled values for paved and gravel would be 50 each according to Table 5.6.

5.1.2.7 Other Factors

Other factors, such as material availability, housing density, and current or future development in the area, are scaled as shown in Table 5.7.

Table 5.7: Scaled Values for Paved and Gravel Roads for Various Factors

Factors	**Material Availability (local material or gravel quarry)**		**Housing Density**			**Development**		
	Near	**Far**	**High**	**Moderate**	**Low**	**Good**	**Moderate**	**Poor**
Scaled value for paved	0	50	100	50	0	100	50	0
Scaled value for gravel	100	50	0	50	100	0	50	100

If the gravel site is far away from the road under consideration and the housing density is moderate with moderate development, then the scaled values for paved and gravel roads can be determined using Table 5.7.

The county official or road supervisor can include any other factors apart from ones mentioned which might be important to consider while deciding on the road surface type, and use their best judgment to give the scaled values to those new factors.

5.1.3 Total Score

Scaled values for a few factors would suggest having a paved road and for others it would suggest gravel road. Thus, a total score was calculated considering all the factors and their respective rates. The roadway surface type with the higher total score is the preferred alternative. The summary of scaled values for paved roads and gravel roads for each of the seven factors is shown in Table 5.8 along with the weightage of each factor.

Table 5.8: Summary of Scaled Values for Paved and Gravel Roads with Weightage for Each Factor

Factors	Weights (Wi)	Scaled value for paved (S_{Pi})	Scaled value for gravel (S_{Gi})
Agency cost	0.25	95.65	100
Safety	0.20	24.08	100
VOC	0.15	100	65
AADT	0.15	40	60
Purpose of road usage	0.15	74	26
Public preference	0.05	50	50
Other factors			
Material availability	0.01	50	50
Housing density	0.02	50	50
Development	0.02	50	50
Total	1.00		

As shown in the summary table, when considering agency cost, VOC, and purpose of road usage, a paved roadway surface is preferred over gravel. When considering safety and traffic volume, however, a gravel roadway surface is preferred. For factors such as public preference, material availability, housing density, and development that have less importance with low weights, the scaled values for paved surfaces and gravel surfaces are identical, showing that either surface is suitable when considering these factors. The overall preference for a roadway surface type is determined by considering all factors and calculating the total score using Equation 4.20 as:

$$\text{Score}_{total} = \sum_{i=1}^{7} W_i * S_i$$

$$\text{If} \left(\sum_{i=1}^{7} W_i * S_i \quad \begin{matrix}\text{for paved}\\ \text{road}\end{matrix} \right) > \left(\sum_{i=1}^{7} W_i * S_i \quad \begin{matrix}\text{for gravel}\\ \text{road}\end{matrix} \right) \quad \begin{matrix}\text{then paved road is preferred}\\ \text{and vice versa.}\end{matrix}$$

For paved road,

$$\text{Score}_{total} = W_1 * S_{P1} + W_2 * S_{P2} + W_3 * S_{P3} + W_4 * S_{P4} + W_5 * S_{P5} + W_6 * S_{P6} + W_7 * S_{P7}$$

$$= 0.25 * 95.65 + 0.20 * 24.08 + 0.15 * 100 + 0.15 * 40 + 0.15 * 74 + 0.05 * 50 + 0.01 * 50 + 0.02 * 50 + 0.02 * 50$$

$$= 65.82$$

For gravel road,

$$Score_{total} = W_1 * S_{G1} + W_2 * S_{G2} + W_3 * S_{G3} + W_4 * S_{G4} + W_5 * S_{G5} + W_6 * S_{G6} + W_7 * S_{G7}$$

$$= 0.25 * 100 + 0.20 * 100 + 0.15 * 65 + 0.15 * 60 + 0.15 * 26 + 0.05 * 50 + 0.01 * 50 + 0.02 * 50 + 0.02 * 50$$

$$= 70.13$$

The alternative with the highest total score is presumed to be the better alternative. Therefore, for the given example, a gravel roadway surface is preferred, with total score of 70.13 compared to a paved roadway surface with a total score of 65.82.

Results of a given situation may vary depending on variation in maintenance details, traffic volume, crash data, and characteristics by county; however, the methodology remains the same. This proposed general guideline is useful for determining the most suitable roadway surface type for any variations and local conditions and preferences.

5.2 Gravel Road Paving Guidelines Program

A computer-based Gravel Road Paving Guidelines Program was developed as a user interface using the same methodology to simply perform calculations for complexities after considering variations. The user interface was developed using Visual Studio 2015 with Visual Basic coding. The user interface accepts the user inputs required to perform the calculations for life-cycle cost (LCC), vehicle operating cost (VOC), performing safety analysis, and selecting local scenario for factors like purpose of road usage, public preference, and other factors. The user inputs are used in the appropriate equations and the scaled values are calculated. Using the survey-calculated weights as default value for each factor and the calculated scaled values, the final score is calculated. Depending on the final score, the user interface suggests a better roadway surface type alternative.

The user interface provides flexibility for any number of activities carried out on paved and gravel roads. All the conditions are considered while developing the user interface. This computer-based program is very simple to use and all basic instructions for the user are provided. The user using best judgment could make any changes to the default values. If any factor is not important according to local agencies, they can omit that factor and redistribute the weights. In addition, a new factor can be incorporated and county officials can use logical reasoning to give the weight. In any case, the total weights of all factors to be considered should sum up to 1.00. Appendix F shows the screenshots of the computer program.

5.3 Cost versus AADT Approach

When only agency cost plus VOC and AADT is considered when determining a roadway surface type, the break-even point can be determined. Key information required for this approach includes uniform information for all considered sections of roadways in order to calculate the break-even point. This uniform information includes maintenance cost per mile, AADT, and VOC per mile. In order to calculate the VOC per mile, details regarding traffic composition, speed limit of the roadway, and gradient and horizontal curvature of the roadway should be known, thereby allowing the previously proposed method to calculate VOC using the computer-based program. If gradient and horizontal curvature information is unknown, it is assumed to be zero.

Data from Riley County, which was in the necessary format to perform the alternative approach of cost versus AADT, was used as an example to demonstrate use of this approach. Project-level details for Riley County were available for 5 years, from 2010 to 2014, and details for all the years were in similar form. Details of maintenance cost were available for a total of 35 paved road sections and 28 gravel road sections. In order to maintain uniformity among all sections to be considered for the alternative approach, a few sections were excluded from analysis. Traffic volume details for three paved sections and three gravel sections were missing; thus, these sections were not included in the analysis. The average maintenance cost for sections throughout the 5 years was considered. The average AADT of those sections was also considered for analysis and to calculate the VOC. Sections with AADT more than 600 vpd were not considered for analysis because those sections were not LVRs and all sections with AADT greater than 600 vpd were paved sections. After omitting sections with missing AADT and AADT greater than 600 vpd, 22 paved sections and 25 gravel sections were used for analysis.

The costs considered for analysis and plotted against AADT included agency cost and user cost. The study in South Dakota also considered agency cost and user cost for plotting against AADT in order to identify the break-even point (Zimmerman & Wolters, 2004). Agency cost includes maintenance cost and initial construction cost. No sections considered for analysis had initial construction cost, so agency cost was only maintenance cost. User cost consisted of the VOC. The average agency cost and average AADT on selected gravel and paved sections are shown in Table 5.9 and Table 5.10, respectively.

Table 5.9: Analysis Details of Gravel Sections in Riley County

Number of sections	Average agency cost/mile	Average AADT
1	$6,563	46
2	$7,815	58
3	$8,418	75
4	$6,554	53
5	$8,757	109
6	$7,741	74
7	$6,129	41
8	$2,920	51
9	$14,989	72
10	$6,124	95
11	$4,556	55
12	$8,590	24
13	$9,995	59
14	$7,035	67
15	$6,884	58
16	$6,359	67
17	$7,090	69
18	$5,542	36
19	$20,013	153
20	$3,935	5
21	$4,991	51
22	$6,830	40
23	$8,105	43
24	$8,032	69
25	$6,854	66

Table 5.10: Analysis Details of Paved Sections in Riley County

Number of sections	Average agency cost/mile	Average AADT
1	$29,400	120
2	$12,793	321
3	$34,742	67
4	$11,549	566
5	$9,412	508
6	$11,020	561
7	$7,093	572
8	$29,178	113
9	$8,744	547
10	$11,512	193
11	$42,160	78
12	$8,535	241
13	$33,816	416
14	$14,369	110
15	$7,278	274
16	$29,177	175
17	$9,668	176
18	$21,262	275
19	$30,701	425
20	$28,226	515
21	$32,803	363
22	$14,960	301

Traffic composition and speed limit information is needed in order to calculate VOC. However, due to unavailability of such information, various traffic volumes and speed limits were considered in order to obtain a proper idea about variation. Six cases were considered, as shown in Table 5.11. The graph plotting for all six cases shows the break-even point for AADT, as shown in Figures 5.2 to 5.7.

Table 5.11: Six Cases for Calculating VOC

Cases	Traffic composition		Speed limit (mph)
	Passenger cars (%)	Trucks (%)	
1	90	10	40
2	80	20	40
3	70	30	40
4	90	10	50
5	80	20	50
6	70	30	50

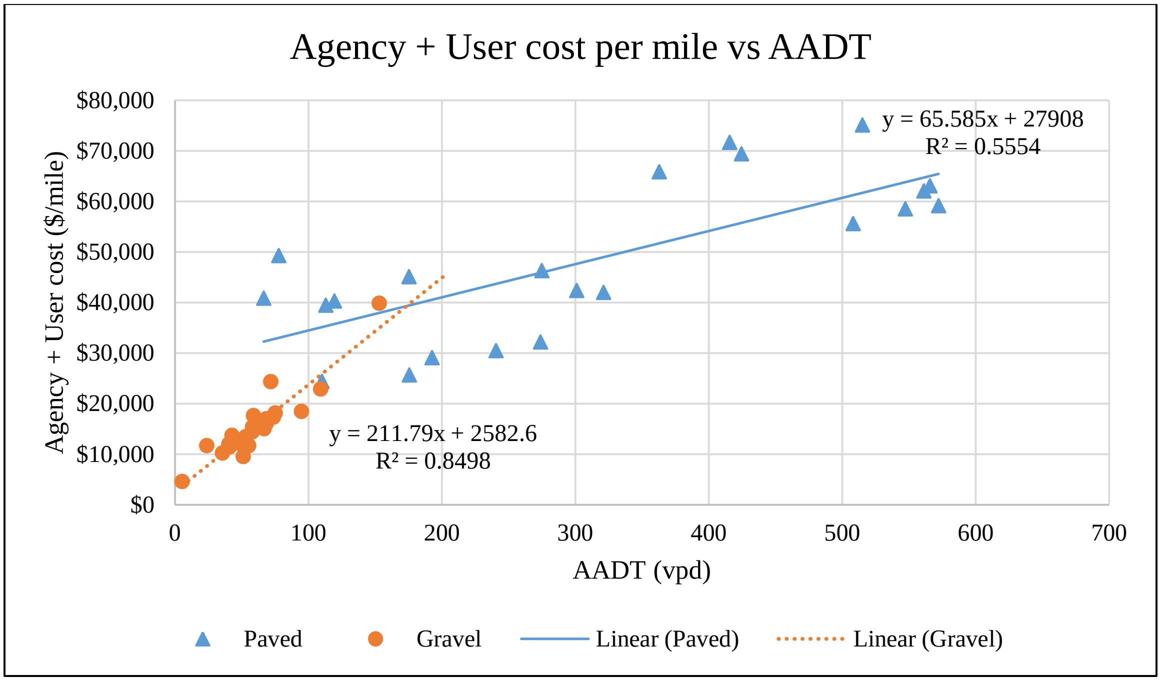


Figure 5.2: Break-Even Point for AADT with Traffic Composition of 90/10 and Speed 40 mph

*Traffic composition of 90/10 means 90% passenger cars and 10% trucks.

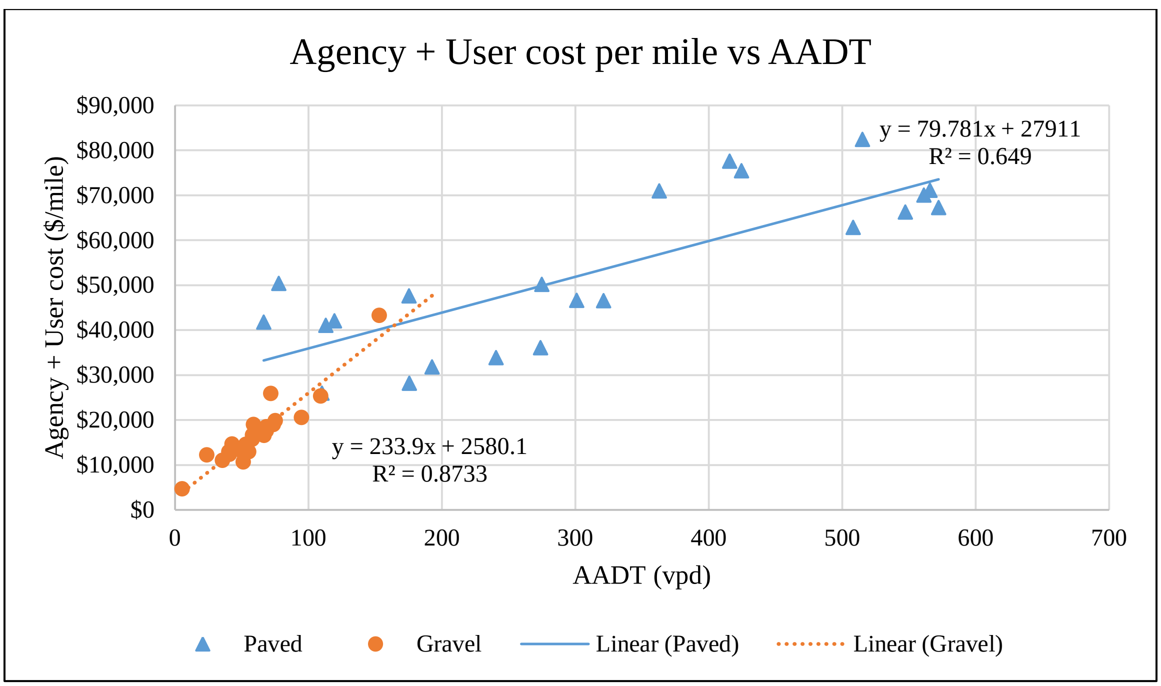


Figure 5.3: Break-Even Point for AADT with Traffic Composition of 80/20 and Speed 40 mph

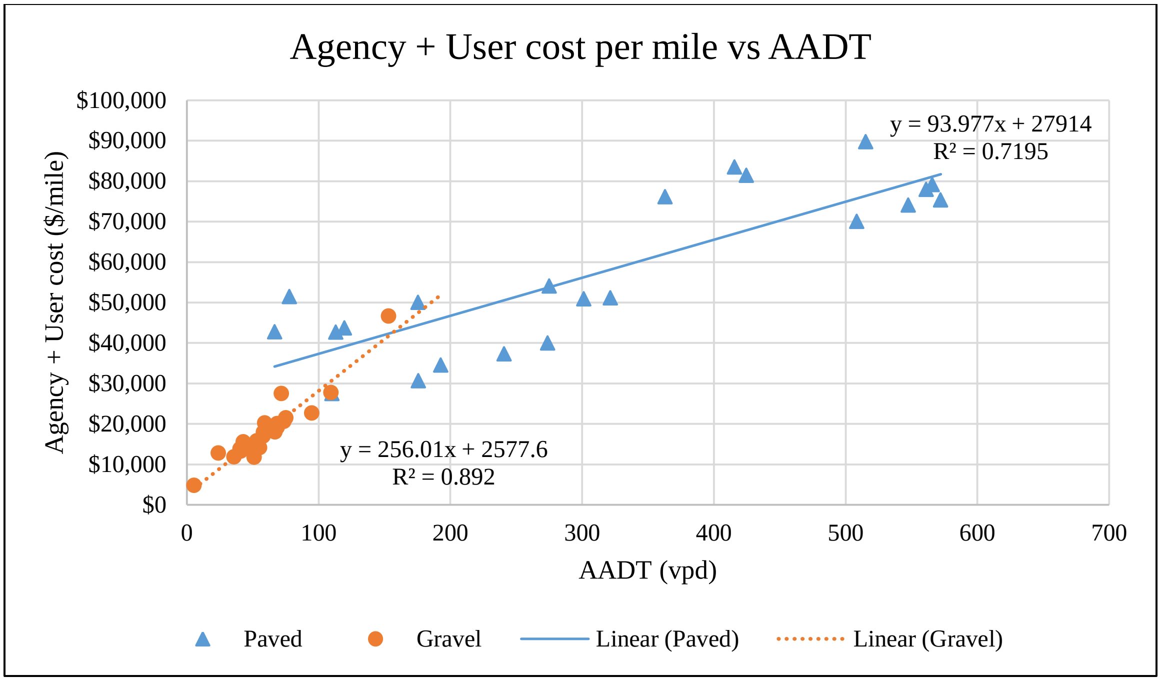


Figure 5.4: Break-Even Point for AADT with Traffic Composition of 70/30 and Speed 40 mph

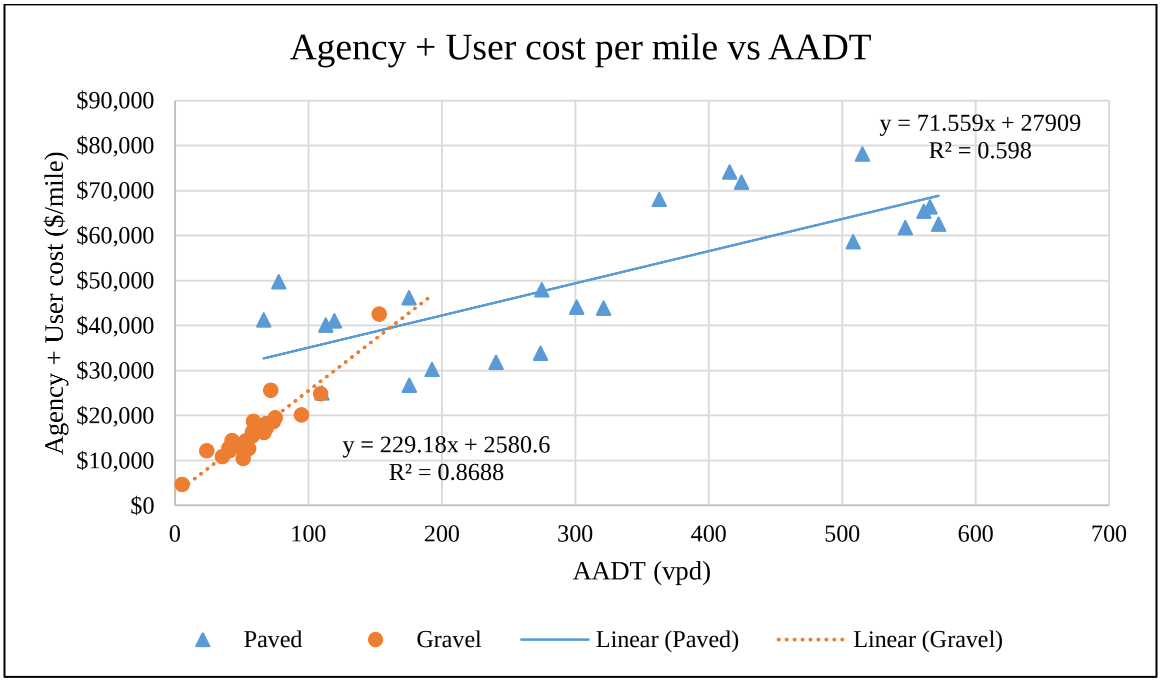


Figure 5.5: Break-Even Point for AADT with Traffic Composition of 90/10 and Speed 50 mph

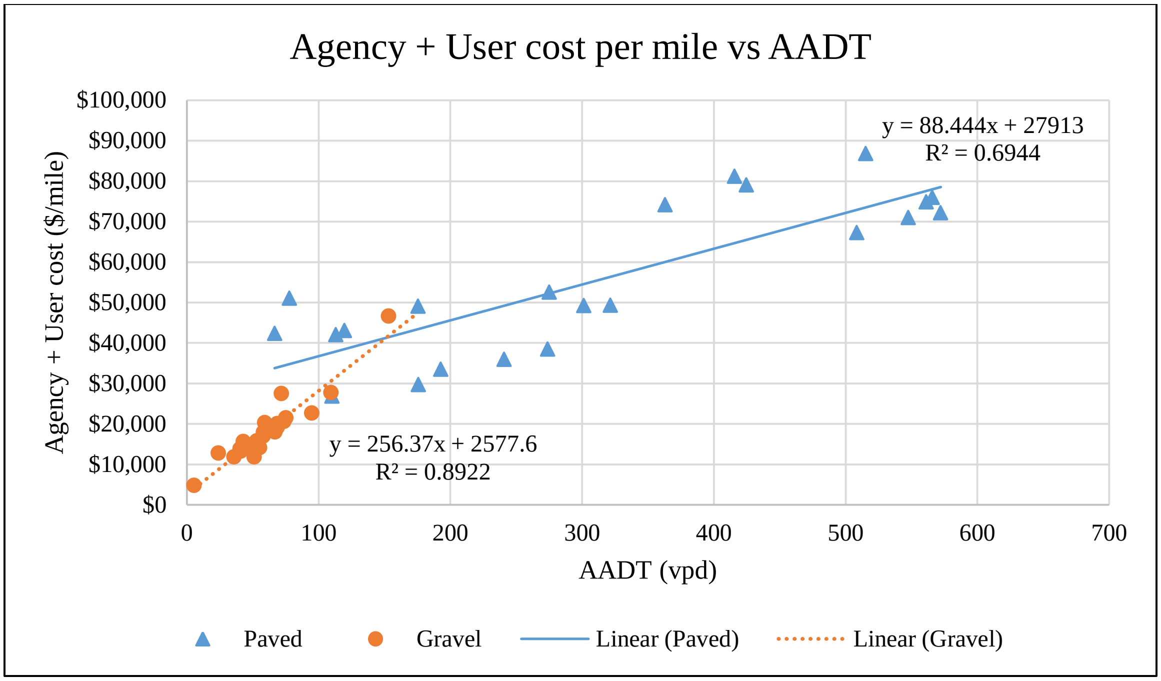


Figure 5.6: Break-Even Point for AADT with Traffic Composition of 80/20 and Speed 50 mph

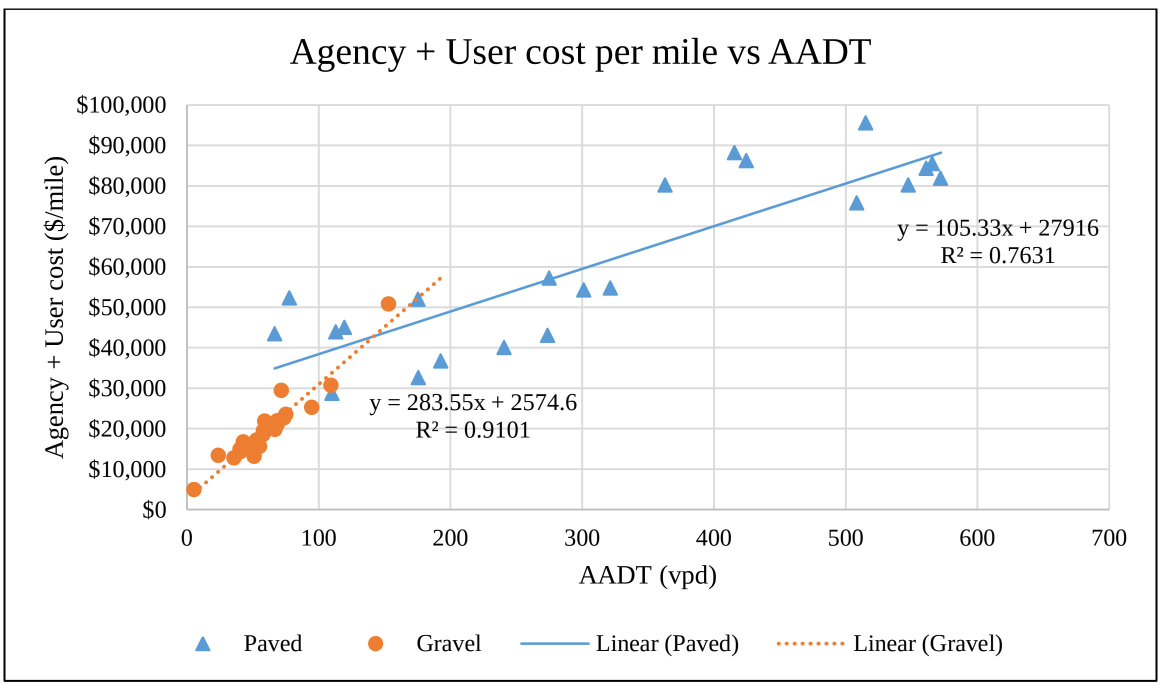


Figure 5.7: Break-Even Point for AADT with Traffic Composition of 70/30 and Speed 50 mph

The break-even point was calculated by simultaneously solving equations of the best fit for gravel roads and paved roads. Table 5.12 summarizes the six cases with break-even points.

Table 5.12: Summary of Six Cases with Break-Even Point for AADT

Cases	Traffic composition		Speed limit (mph)	Break-even point (vpd)
	Passenger cars (%)	Trucks (%)		
1	90	10	40	173
2	80	20	40	164
3	70	30	40	156
4	90	10	50	161
5	80	20	50	151
6	70	30	50	142

The summary shows that the break-even point for traffic volume decreased with an increased percentage of trucks and with increased speed limit. However, the break-even point was specific to the Riley County data available for the years 2010 to 2014, suggesting a potential different break-even point for other counties with unique maintenance costs per mile and corresponding traffic volumes.

Chapter 6: Summary, Conclusions, and Recommendations

There is a wide variation of traffic volumes across different regions, with very low traffic volume in remote rural areas with gravel surface and higher traffic volume on rural roads with paved surface. In addition, variations in local conditions and scenarios create a challenge for local agencies to determine suitable roadway surface types for local rural roads when considering constraints on transportation budgets. The primary objective of this research was developing standardized guidelines to identify the most suitable roadway surface for a particular roadway section with given conditions.

The literature review suggested that LCC analysis should be used for the comparison of paved roadway surface costs and gravel roadway surface costs. Various studies used the *Economic Analysis for Highways* by Winfrey to calculate the VOC. The literature proved that although no magical number for traffic volume can determine optimal roadway surface type, various studies have considered paving gravel roads with traffic volume below 200 vpd. The literature also asserted that local rural paved road surfaces are safer, showing decreased crash rates, compared to unpaved road surfaces.

Two surveys were conducted for this research. An out-of-state survey was initially conducted in order to determine the functioning of other states with respect to their local rural roads. Then a survey was given to Kansas counties in order to obtain details on maintenance trends and traffic volume information from various counties in Kansas. The Kansas county survey had a good response rate of 74%, totaling 77 out of 105 Kansas counties. The Likert scale was used to record responses pertaining to the importance of factors. Converting the Likert responses to scaled values showed that agency cost (initial maintenance cost and maintenance cost) was the most important factor to be considered when deciding whether or not to implement a surface conversion. Safety was the second important factor, with a scaled value of 0.85. When considering the purpose of road usage, heavy vehicle routes were most important, with a scaled value of 0.83, and should be considered first for paving such routes.

Detailed information was further obtained from six counties in Kansas: Douglas County, McPherson County, Morris County, Riley County, Trego County, and Washington County. These counties had varying geographical features and variation in percentage of gravel and paved roads. For Douglas County, the overall average maintenance cost from 2010 to 2014 was $3,794 per mile for paved roads and $10,428 per mile for gravel roads. In Riley County, the average maintenance cost for paved roads and gravel roads was $33,010 per mile and $7,307 per mile, respectively, from 2010 to 2014. For McPherson County, the average cost for HMA overlay is approximately $104,000 per mile, the cost for chip sealing is $18,200 per mile, the cost for crack sealing, patching, and stabilizing is $11,700 per mile, and the cost for blading, resurfacing, and spot/regravelling is $4,800 per mile. The average maintenance cost for paved roads and gravel roads in Washington County from 2012 to 2014 was $11,394 per mile and $3,389 per mile, respectively. For Morris County, the average cost of maintenance from 2012 to 2014 for gravel roads was $1,873 per mile and $8,452 per mile for paved roads. Trego County, which only maintains gravel roads, had an average maintenance cost per mile as $2,287 from 2010 to 2014.

The initial construction cost, or conversion cost, for a paved road for Lyon County was $408,600 per mile in 2013-dollar value. The conversion cost for gravel surface to paved surface for McPherson County was $680,850 per mile in 2013-dollar value. The conversion cost for paved surface to gravel surface for Washington County was $53,500 per mile in 2013-dollar value.

For Kansas, the average EPDO crash rate was higher on gravel roads, totaling 1,427.22 crashes per hundred million VMT compared to only 851.57 crashes per hundred million VMT on paved roads during the analysis period from 2010 to 2014. This illustrates that paved roads in Kansas are safer than gravel roads.

Scaled values for each important factor for consideration when determining whether or not to convert a particular roadway surface type were also explained. Using weights of each factor and multiplying it with the corresponding scaled value of that factor, a score was calculated. This final score was compared for paved road surfaces and gravel road surfaces. The alternative with the highest score value was recommended under the selected criteria or local conditions and situations.

The general guideline involves use of the equations mentioned in methodology to perform calculations and consider all the factors together to get the final score for paved surface and gravel surface. The guideline developed in this research is very flexible and can incorporate all variations with respect to maintenance details, traffic volume, or other factors such as road usage, public factors, etc. A computer-based program was developed as a user interface using the same methodology in order to simplify calculation related complexities when considering variations. The program overall helps complete the calculations after taking user inputs in a systematic way.

County officials can use this user-interface tool to input local suitable variable values in order to determine the optimally suitable and economical roadway surface type for given conditions.

The weights developed for each factor are based on the survey responses from counties in Kansas. Though the guideline would remain the same, the weights might differ in different regions depending on the different roadway conditions and maintenance practices. Thus, it would be recommended to use the best judgement to select the factors and weights to those factors. The weight value obtained from counties in Kansas can be used as default.

This research considers the safety analysis for identifying a preferred surface type alternative. Further research can be carried out to determine if the crash cost would have significant impact on the decision of selecting a better roadway surface type.

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Appendix A: Summary of Road System Type in Kansas

This appendix shows the name and number of Kansas counties classified by road system type.

Table A.1: Non-County Unity Road System (County Township System)

This road system includes 35 counties.

Atchison	Edwards	Meade	Russell
Barber	Ellsworth	Mitchell	Sedgwick
Barton	Ford	Nemaha	Shawnee
Brown	Greenwood	Osage	Stafford
Butler	Harvey	Osborne	Sumner
Cowley	Kingman	Pawnee	Thomas
Decatur	Logan	Reno	Wabaunsee
Dickinson	Marshall	Rice	**Washington**
Douglas	**McPherson**	**Riley**	

Table A.2: County Unit Road System

This road system includes 67 counties.

Allen	Geary	Lane	Rooks
Anderson	Gove	Lincoln	Rush
Bourbon	Graham	Linn	Saline
Chase	Grant	Lyon	Scott
Chautauqua	Gray	Marion	Seward
Cherokee	Greeley	Miami	Sheridan
Cheyenne	Hamilton	Montgomery	Sherman
Clark	Harper	**Morris**	Smith
Cloud	Haskell	Morton	Stanton
Coffey	Hodgeman	Neosho	Stevens
Comanche	Jackson	Ness	**Trego**
Crawford	Jefferson	Norton	Wallace
Doniphan	Jewell	Ottawa	Wichita
Elk	Johnson	Phillips	Wilson
Ellis	Kearny	Pratt	Woodson
Finney	Kiowa	Rawlins	Wyandotte
Franklin	Labette	Republic	

Table A.3: General County Rural Highway System (County-Rural System)

This road system includes three counties.

Clay	Leavenworth	Pottawatomie

NOTE: Counties marked in bold font provided project-level details for research.

Appendix B: Copies of Survey Questionnaire

This appendix shows the draft of the survey questionnaire used for this research.

B.1 Out-of-State Survey

<u>SURVEY ON GRAVEL ROAD PAVING GUIDELINES</u>

Your Name: State/county that you are representing:
E-mail: Contact Number: Date:

Please mark the most appropriate box or fill in the blanks.

NOTE: Do not include roads inside residential subdivisions.

1. Does your state/county have standards for type of improvement made when going from gravel road to paved road or vice versa? ○ Yes ○ No

2. Is it an acceptable practice to pave an existing gravel road without improvements to cross-section, and horizontal & vertical alignment? ○ Yes ○ No
When is it acceptable?

3. How would you rank the importance of following factors in deciding whether to upgrade a gravel road to a paved road or vice versa? (Check all that apply)

Factors	Very important	Important	Moderately important	Less important	Not important
Initial Construction Cost	○	○	○	○	○
Maintenance Cost	○	○	○	○	○
ADT on that road	○	○	○	○	○
Dust pollution	○	○	○	○	○
Frequency of maintenance	○	○	○	○	○
Safety	○	○	○	○	○
Primary purpose of the road (regular traffic, for farmers and local people, higher truck traffic, etc.)	○	○	○	○	○
Others (Specify) ________________	○	○	○	○	○

4. How did you or would you rank the importance of following factors when converting a gravel road to a paved road? (Check all that apply)

Factors	Very important	Important	Moderately important	Less important	Not important
Pavement Width	○	○	○	○	○
Shoulder Width	○	○	○	○	○
Design Speed	○	○	○	○	○
Clear Zone	○	○	○	○	○
Fore slope	○	○	○	○	○
Others (Specify) _______________	○	○	○	○	○

5. Are there any other suggestions or ideas to help us develop better guidelines?

B.2 Kansas County Survey

SURVEY ON GRAVEL ROAD PAVING GUIDELINES

Your Name:	County that you are representing:	
E-mail:	Contact Number:	Date:

Please mark the most appropriate box or fill in the blanks.

1. Did your county convert any gravel road to paved road during the last 5 years? ◯ Yes ◯ No
2. Did your county convert any paved road to gravel road during the last 5 years? ◯ Yes ◯ No
3. If answered 'yes' to Q.1 or Q.2, then how did you make the decision to change the roadway surface type?

4. Were there any geometric changes made in the road while converting the road surface type? ◯ Yes ◯ No
   If yes, please list them down.

5. What would be the approximate range of Average Daily Traffic (ADT) on the roads at your jurisdiction?

	Minimum		Maximum	
On Gravel roads		vpd		vpd
On Paved roads		vpd		vpd

vpd: vehicles per day

6. How would you rank the importance of following factors in deciding whether to upgrade a gravel road to a paved road or vice versa? (Check all that apply)

Factors	**Very important**	**Important**	**Moderately important**	**Less important**	**Not important**
Initial Construction Cost	◯	◯	◯	◯	◯
Maintenance Cost	◯	◯	◯	◯	◯
ADT of the road	◯	◯	◯	◯	◯
Safety	◯	◯	◯	◯	◯
Frequency of maintenance	◯	◯	◯	◯	◯
Drainage	◯	◯	◯	◯	◯
Purpose of road usage					
Heavy vehicle route	◯	◯	◯	◯	◯
Retail and commercial route	◯	◯	◯	◯	◯
Parks and community route	◯	◯	◯	◯	◯
Government facility route	◯	◯	◯	◯	◯
School route	◯	◯	◯	◯	◯
Farm to market route	◯	◯	◯	◯	◯
Church access route	◯	◯	◯	◯	◯
Residential mail route	◯	◯	◯	◯	◯
Others (Specify) _______________	◯	◯	◯	◯	◯

7. Does your county keep a track of project level information (construction and/or maintenance cost, ADT, types of improvements, etc.) for various roadway sections? ◯ Yes ◯ No
   If yes, can the project level information be made available for the research purpose? ◯ Yes ◯ No

Appendix C: Survey Comments

C.1 Out-of-State Survey

One of the question from survey questionnaire for other states asks about other suggestions or general recommendations or comments to come up with a better guideline to decide appropriately when to convert a gravel road to paved road and vice versa.

The important comments from various states and counties within the states are quoted below.

Q. 5 Are there any other suggestions or ideas to help us develop better guidelines?

Comments:

I would be far more interested in standards for returning old tired paved roads to gravel in a way that would limit the cost of future maintenance. That is what I am seeing as the most likely scenario going forward. I do not anticipate paving of any current gravel roads due to severely constrained budgets.
Most counties are not paving roads due to limited budgets and declining (migrating) populations
If you cannot afford to build it correctly in the first place you will not be able to maintain it in the future.
Linn county, Iowa uses 400vpd for planning hard surfacing a rock road by shaping 30' top, macadam rock base 6" thick, and placing two seal coats over two year span. Linn county uses 1000 vpd for planning 8" PCC overlay of existing hard surfacing. Linn county uses 200 vpd for CaCl2 Safety dust control.
Make sure that your current funding can support any proposed upgrade.
We are in a budget problem where we are no longer paving new roads. We cannot afford expected resurfacing costs on our current HMA surfaced roads at this time. Unless some new revenue source becomes available soon, the condition of our paved road system will degrade. Unless we have some local participation from the adjacent landowners in cost, we are not expanding our paved road system.
I think it would be important to establish some guidelines for traffic counts at which it is reasonable to make minimal improvements to cross section and alignment when converting from gravel to pavement.
A road manager can influence, to a certain degree, where traffic moves. There should be some element in the guide that assists in reviewing the role the road plays in the overall road network and assuring the road being upgraded or downgraded fits the need it should ultimately fill.
Any standard you come up with should be open ended to allow the engineer to way the facts in the area and come up with the best solution to the existing problems.
We tried some polymer on gravel roads but it takes about 5 treatments and for that cost you could have double chip n seal or lay 2 inches of asphalt. So doing cost comparisons is very good up front. Upgrading low volume roads are always a cost decision but they need to be safe and maintained as well as the major flowing roads
Stress the importance of frequency of travel and load factor
Ask construction companies what the best techniques are
We use traffic counts for justification. All are low volume roads, but if have a daily average of 100 and another road has average of 65, 100 will take precedent every time. I also look at number of residents per mile average. Several ways to justify using only numbers. Have to keep names out of the decisions.
As far as setting your roads on before you chip seal or pave. I am new with the county but what I have seen so far is most to all roads in the past were set up wrong. Your final product is only going to be as good as the material that you used to set up your sub-grade and base. With that being said if you are going to use bad material to set your roads up then you’re better off to just leave them dirt and just add pit as needed to keep traffic flowing smooth.

C.2 Kansas County Survey

One of the question from survey questionnaire for the counties in Kansas enquires about the reason why the county did or county would consider to convert the gravel road to paved road and vice versa.

The comments from various counties on this question is quoted below.

Q. 3. If the county converted a gravel road to paved road or vice versa during last 5 years, then how was the decision made to change the roadway surface type?

(a) For converting gravel road to paved road

Poor soil base (sandy soil) near a recreation pond.
Amount of traffic and type of traffic
Traffic count
Amount of truck traffic to local dairy
Commissioner
A new business came in
A local program where candidate projects were identified and then programed based upon acquisition of the necessary easements by donation of the property owners.
Westar built a new Peak Power Station on a gravel road and paid for placing asphalt on the access roads to the plant.
Requested by local business
Traffic count exceed 250 vpd
Landowner went together and paid for it
Mostly by traffic volume
Citizen pressure on County Commissioners
County took over the maintenance of a section of gravel road from a township and, since all of the other roads under the County maintenance are hard surface, we converted this road from gravel to chip/seal.
The road was a township road, but the township could not maintain the road with a 750 a day vehicle count. The county and township joined in the expense and the county contracted the road construction out and paved the road. The township payed the county $10,000.00 a year for 10 years for their part, and the county took over maintaining the road after that.

(b) For converting paved road to gravel road

Cost of maintenance
Cost analysis
Low volume of traffic. No money to redo
Asphalt was beyond repair and too expensive
Budget and have another paved road one mile away
Maintenance Expenses

(c) For converting gravel road to paved road and paved road to gravel road

User request and traffic volume
Traffic count, roadway conditions, budget
Maintaining gravel road with between 40 and 50 heavy truck traffic count was not cost effective. Completed return to gravel to finish a road that had been started but not completed in finishing the entire length of road.

C.3 Additional Comments and Information from a Few Kansas Counties

Table C.1: Information from a Few Kansas Counties Regarding Converting Gravel Surface to Paved Surface

County	Pave Section line roads	Pave an existing gravel road	Pavement Width	Shoulder Width	Fore slope	Clear Zone	Design Speed	Cost/Mile
McPherson	Yes	No	24	4	4:1	10	55	$600,000
Miami	Yes	If already improved in the past	24	2	3:1	Depends		$120,000 for only materials
Johnson	Yes	No	24	0	4:1	10	35	$500,000
Saline	Yes	No	24	5	4:1	AASHTO	55	$1,000,000
Shawnee	No							
Douglas	Last in 1994	No	24	6	4:1	AASHTO	55	
Riley	Last in 1998	No	24	2	3 or 4:1	Depends		$1,300,000

Miami: Have paved some roads that were improved in the past and remained gravel, we see this as staged construction so current design standards would not apply. We have paved some local gravel roads near cities that we expect the road to be annexed and improved by the city. The Miami County has over 17,000 residents (and counting) in the un-incorporated area with majority in the Northern half. The goal is to apply a chip-seal or magnesium surface on all roads exceeding 250 vehicles per day. Collector routes that have not been improved in the past are not paved but have a dust-control surface. The county will then apply AASTO standards or some other acceptable standard for the improvement to these type of roads. The County is in the process of posting all local roads at 35 mph. The county has been converting around five miles of roadway from gravel to paved per year. All work is done in-house with the price being materials only. Miami County is a County-Unit system therefore the majority of roads we now pave are old “Township Roads”. The standards for these are different from the collector routes. When we improve a road to AASHTO standards, we budget 1 to 1.2 million dollars per mile depending on right of way (ROW), utilities and topography.

Johnson: Is it an acceptable practice to pave an existing gravel road without improvements to cross section, and horizontal and vertical alignment? Our current practice is to improve the cross section but not the horizontal and vertical alignment. If so, do you post a speed limit? We leave current posting at 35 mph unless the vertical and horizontal alignment warrant increasing to 45 mph.

Saline: $1 million for preliminary estimating purposes but can be more based on land acquisition costs, terrain, and drainage requirements. Not "acceptable" to me to pave a gravel road unless directed by elected officials to do so. It would be a waste of money. We do post speed limits on paved roads.

Douglas: The last project we did to convert a gravel section line road to a paved road was around 1994. It was total reconstruction of Route 1029 between Route 442 (Stull Road) and US-40. As I recall the cost was approximately $1,000,000/mile. It would not be acceptable to pave an existing gravel road unless it met geometric standards. We use design standards in KDOT's *"Project Development Manual for Non-National Highway System Local Government Road and Street Projects*," *Appendix B*. In the only two projects in which I have been involved to convert gravel section line roads to paved roads, we have reconstructed the roads to meet design standards.

Shawnee: Shawnee County has not converted gravel roads to paved in my time as PWD.

Riley: One shoe does not fit every situation. We have not converted a gravel road to paved for about 12 years and so all we did was provide a little calcium chloride to the gravel near the shoulders and then put 6 inches of asphalt on it. Needless to say we are having base issues with this road. Our policy now is to:

Look at the horizontal and vertical and make changes where practical and feasible (can become expensive in a hurry)

Provide for subgrade modification

Work on the cross-section which would include a small shoulder (need something to put up against the asphalt or narrow road)

Minimum 24 feet wide

Minimum shoulder 2 feet

Minimum foreslope: 3:1 prefer 4:1

Clear zone : is dependent upon traffic count and posted speed

Design speed: If the horizontal and vertical alignments were altered, we would require a full set of plans done with the road designed to a particular speed. We would then either sign it that speed or place advisories at curves, hills, etc. Where a reduction in speed is warranted.

If there are only minor vertical and horizontal alignment changes we would not post a speed limit but would use advisory signing

Is it acceptable practice to just pave a gravel road: No, I do not believe so but there will always be a political component to this decision. All we can do is recommend the proper thing to do and if they choose to go a different direction, we have done our due diligence.

We currently have an asphalt road we are reconstructing: (this is similar to moving a gravel road to asphalt)

It includes a re-alignment (some row purchase)

Structure lengthening not replacement

Adding shoulders

Sub-grade modification

Some curb and gutter

Some retaining walls

This project is about 1.8 million per mile remove the retaining walls, curb, and gutter will get it below 1.5 million. So based on this one and other projects we feel a good cost is 1.2 to 1.5 million per mile. It will depend on how much ROW and vertical and horizontal alignment is needed.

Appendix D: Tables from Economic Analysis for Highways

This appendix presents a series of tables for five typical vehicle classes, including cost values on good roadway pavement (paved surface) at uniform speed (Table D.1 to Table D.5), gradient (Table D.6 to Table D.10), and additional vehicle costs for along the horizontal curvature (Table D.11 to Table D.15). This appendix also presents a table with a conversion factor to convert the running cost from paved surface to gravel surface (Table D.16).

NOTE: All cost values are 1970-dollar values.

UNIT: Dollars per 1,000 vehicle miles for Tables D.1 to D.15

Table D.1: VOC at Uniform Speed for 4-kip Passenger Car

Speed (mph)	Running cost by item					Total cost
	Fuel	Tires	Engine oil	Maintenance	Depreciation	
5.00	23.55	0.18	4.22	5.38	26.03	59.36
7.50	17.50	0.28	3.20	5.43	23.45	49.86
10.00	14.56	0.38	2.64	5.49	21.86	44.93
12.50	12.83	0.49	2.27	5.57	20.66	41.82
15.00	11.75	0.60	2.03	5.67	19.68	39.73
17.50	11.04	0.71	1.86	5.79	18.81	38.21
20.00	10.56	0.82	1.75	5.93	18.03	37.09
22.50	10.21	0.94	1.67	6.09	17.32	36.23
25.00	10.01	1.06	1.64	6.25	16.67	35.63
27.50	9.89	1.19	1.61	6.42	16.08	35.19
30.00	9.84	1.32	1.60	6.60	15.55	34.91
32.50	9.89	1.46	1.59	6.78	15.07	34.79
35.00	9.96	1.60	1.59	6.97	14.64	34.76
37.50	10.10	1.75	1.58	7.16	14.25	34.84
40.00	10.28	1.90	1.58	7.36	13.91	35.03
42.50	10.49	2.06	1.56	7.56	13.60	35.27
45.00	10.76	2.23	1.55	7.77	13.32	35.63
47.50	11.06	2.41	1.52	7.98	13.16	36.13
50.00	11.41	2.61	1.49	8.19	12.83	36.53
52.50	11.80	2.81	1.43	8.41	12.62	37.07
55.00	12.24	3.03	1.37	8.64	12.43	37.71
57.50	12.72	3.27	1.38	8.88	12.25	38.50
60.00	13.25	3.53	1.43	9.13	12.08	39.42
62.50	13.85	3.81	1.50	9.40	11.93	40.49
65.00	14.51	4.12	1.61	9.69	11.78	41.71
67.50	15.25	4.46	1.76	10.01	11.64	43.12
70.00	16.10	4.85	1.93	10.37	11.51	44.76
72.50	17.04	5.30	2.13	10.78	11.38	46.63
75.00	18.10	5.83	2.36	11.25	11.25	48.79
77.50	19.34	6.45	2.64	11.79	11.12	51.34
80.00	20.79	7.19	2.96	12.41	11.00	54.35

Source: Winfrey (1969)

Table D.2: VOC at Uniform Speed for 5-kip Commercial Delivery Truck

Speed (mph)	Running cost by item					Total cost
	Fuel	Tires	Engine oil	Maintenance	Depreciation	
5.00	23.72	0.22	3.53	6.56	30.32	64.35
7.50	17.62	0.34	2.67	6.62	27.32	54.57
10.00	14.65	0.46	2.21	6.70	25.47	49.49
12.50	12.94	0.59	1.91	6.80	24.07	46.31
15.00	11.86	0.72	1.72	6.92	22.93	44.15
17.50	11.15	0.85	1.58	7.06	21.91	42.55
20.00	10.69	0.98	1.49	7.23	21.00	41.39
22.50	10.41	1.13	1.43	7.43	20.18	40.58
25.00	10.25	1.27	1.39	7.62	19.42	39.95
27.50	10.19	1.43	1.37	7.83	18.73	39.55
30.00	10.21	1.58	1.36	8.05	18.12	39.32
32.50	10.32	1.75	1.34	8.27	17.56	39.24
35.00	10.49	1.92	1.32	8.50	17.06	39.29
37.50	10.74	2.10	1.30	8.74	16.60	39.48
40.00	11.07	2.28	1.29	8.98	16.21	39.83
42.50	11.48	2.47	1.27	9.22	15.84	40.28
45.00	11.97	2.68	1.23	9.48	15.52	40.88
47.50	12.56	2.89	1.22	9.74	15.33	41.74
50.00	13.27	3.13	1.15	9.99	14.95	42.49
52.50	14.08	3.37	1.07	10.26	14.70	43.48
55.00	15.07	3.64	0.99	10.54	14.48	44.72
57.50	16.24	3.92	0.97	10.83	14.27	46.23
60.00	17.69	4.24	0.97	11.14	14.07	48.11
62.50	19.43	4.57	1.00	11.47	13.90	50.37
65.00	21.56	4.94	1.06	11.82	13.72	53.10
67.50	23.91	5.35	1.13	12.21	13.56	56.16
70.00	26.60	5.82	1.22	12.65	13.41	59.70

Source: Winfrey (1969)

Table D.3: VOC at Uniform Speed for 12-kip Single Unit Truck

Speed (mph)	Running cost by item					Total cost
	Fuel	Tires	Engine oil	Maintenance	Depreciation	
5.00	38.12	0.48	3.43	19.32	37.73	99.08
7.50	29.62	0.74	2.67	18.99	33.33	85.35
10.00	25.46	1.00	2.17	18.92	30.13	77.68
12.50	23.06	1.29	1.96	19.02	27.53	72.86
15.00	21.50	1.58	1.79	19.27	25.48	69.62
17.50	20.46	1.87	1.67	19.64	23.73	67.37
20.00	19.76	2.16	1.60	20.13	22.25	65.90
22.50	19.28	2.48	1.54	20.71	21.08	65.09
25.00	18.94	2.80	1.48	21.39	20.12	64.73
27.50	18.73	3.14	1.44	22.14	19.31	64.76
30.00	18.64	3.48	1.40	22.98	18.61	65.11
32.50	18.64	3.85	1.37	23.88	17.01	64.75
35.00	18.72	4.22	1.33	24.85	17.48	66.60
37.50	18.86	4.62	1.29	25.88	17.01	67.66
40.00	19.08	5.02	1.24	26.94	16.59	68.87
42.50	19.38	5.44	1.18	28.06	16.21	70.27
45.00	19.76	5.89	1.12	29.21	15.86	71.84
47.50	20.24	6.36	1.06	30.39	15.55	73.60
50.00	20.80	6.89	1.05	31.59	15.26	75.59
52.50	21.48	7.42	1.07	32.82	15.00	77.79
55.00	22.30	8.00	1.11	34.06	14.77	80.24
57.50	23.24	8.63	1.13	35.30	14.56	82.86
60.00	24.36	9.32	1.25	36.54	14.37	85.84
62.50	25.66	10.06	1.34	37.79	14.20	89.05
65.00	27.16	10.88	1.45	39.04	14.04	92.57

Source: Winfrey (1969)

Table D.4: VOC at Uniform Speed for 40-kip 2-S2 Heavy Truck (Gasoline)

Speed (mph)	Running cost by item					Total cost
	Fuel	Tires	Engine oil	Maintenance	Depreciation	
5.00	145.80	0.97	2.54	30.91	50.79	231.01
7.50	97.87	1.48	1.92	30.38	45.01	176.66
10.00	74.29	2.00	1.63	30.28	40.44	148.64
12.50	60.26	2.54	1.43	30.44	36.81	131.48
15.00	51.03	3.11	1.30	30.83	33.90	120.17
17.50	44.55	3.70	1.21	31.43	31.54	112.43
20.00	39.82	4.34	1.15	32.21	29.58	107.10
22.50	36.29	4.97	1.11	33.14	27.96	103.47
25.00	33.61	5.68	1.07	34.22	26.61	101.19
27.50	31.61	6.39	1.04	35.43	25.46	99.93
30.00	30.11	7.16	1.01	36.76	24.47	99.51
32.50	29.07	8.00	0.98	38.21	23.61	99.87
35.00	28.40	8.86	0.96	39.76	22.86	100.84
37.50	28.08	9.81	0.93	41.40	22.21	102.43
40.00	28.10	10.82	0.89	43.11	21.63	104.55
42.50	28.44	11.91	0.85	44.89	21.12	107.21
45.00	29.12	13.09	0.82	46.73	20.67	110.43
47.50	30.19	14.36	0.78	48.62	20.28	114.23
50.00	31.70	15.74	0.78	50.55	19.93	118.70
52.50	33.80	17.25	0.80	52.51	19.62	123.98
55.00	36.59	18.91	0.84	54.49	19.50	130.33
57.50	40.14	20.73	0.89	56.48	19.11	137.35
60.00	44.55	22.68	0.95	58.47	18.90	145.55

Source: Winfrey (1969)

Table D.5: VOC at Uniform Speed for 50-kip 3-S2 Heavy Truck (Diesel)

Speed (mph)	Running cost by item					Total cost
	Fuel	Tires	Engine oil	Maintenance	Depreciation	
5.00	64.70	1.30	5.15	28.51	67.06	166.72
7.50	44.16	2.00	4.01	28.20	57.98	136.35
10.00	34.05	2.68	3.34	28.22	51.91	120.20
12.50	28.11	3.40	2.94	28.43	47.23	110.11
15.00	24.30	4.17	2.67	28.82	43.45	103.41
17.50	21.68	4.94	2.49	29.38	40.35	98.84
20.00	19.86	5.77	2.37	30.05	37.76	95.81
22.50	18.54	6.61	2.27	30.90	35.57	93.89
25.00	17.62	7.56	2.18	31.88	33.68	92.92
27.50	17.02	8.49	2.10	32.97	32.06	92.64
30.00	16.64	9.50	2.03	34.18	30.67	93.02
32.50	16.45	10.60	1.96	35.51	29.48	94.00
35.00	16.46	11.75	1.90	36.96	28.44	95.51
37.50	16.67	12.99	1.82	38.48	27.53	97.49
40.00	17.06	14.33	1.71	40.04	26.71	99.85
42.50	17.63	15.76	1.60	41.65	25.97	102.61
45.00	18.38	17.32	1.49	43.31	25.30	105.80
47.50	19.34	19.01	1.37	45.03	24.70	109.45
50.00	20.53	20.83	1.32	46.80	24.15	113.63
52.50	21.95	22.84	1.33	48.60	23.65	118.37
55.00	23.66	25.04	1.37	50.41	23.18	123.66
57.50	25.68	27.46	1.44	52.24	22.30	129.12
60.00	26.43	30.06	1.54	54.09	22.48	134.60

Source: Winfrey (1969)

Gradient

Table D.6: VOC at Varying Gradient for 4-kip Passenger Car

Speed (mph)	Minus grade (%)								Level	Plus grade (%)							
	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
5.00	57.36	56.06	55.35	54.82	54.50	54.23	54.14	57.77	59.36	61.27	63.29	65.46	67.68	70.33	72.53	75.23	78.49
7.50	47.29	46.16	45.43	45.04	44.75	44.61	44.53	48.23	49.86	51.81	53.90	56.09	58.35	60.57	63.24	66.02	69.28
10.00	41.94	40.92	40.24	39.88	39.62	39.50	39.42	43.25	44.93	46.89	49.01	51.24	53.53	55.59	58.46	61.31	64.57
12.50	38.48	37.54	36.89	36.59	36.33	36.21	36.83	40.11	41.82	43.81	46.00	48.23	50.52	52.77	55.55	58.44	61.70
15.00	36.04	35.17	34.58	34.29	34.05	33.92	35.14	37.98	39.73	41.74	43.94	46.20	48.50	51.00	53.58	56.49	59.78
17.50	34.16	33.36	32.82	32.54	32.32	32.19	34.00	36.34	38.21	40.23	42.47	44.72	47.05	49.47	52.16	55.13	58.41
20.00	32.69	31.95	31.44	31.16	30.96	30.82	32.95	35.24	37.09	39.12	41.37	43.66	45.99	48.49	51.12	54.14	57.41
22.50	31.50	30.83	30.34	30.10	29.90	30.31	32.41	34.39	36.23	38.31	40.55	42.88	45.21	47.71	50.37	53.42	56.69
25.00	30.56	29.94	29.47	29.24	29.04	29.98	31.90	33.76	35.63	37.72	39.96	42.27	44.62	47.12	49.83	52.93	56.20
27.50	29.80	29.20	28.78	28.52	28.34	29.67	31.50	33.30	35.19	37.28	39.53	41.86	44.22	46.74	49.48	52.60	55.90
30.00	29.15	28.60	28.20	27.94	28.04	29.46	31.24	33.00	34.91	37.02	39.27	41.62	43.99	46.52	49.27	52.46	55.79
32.50	28.69	28.17	27.77	27.51	27.99	29.38	31.12	32.85	34.79	36.88	39.12	41.45	43.87	46.43	49.21	52.39	55.78
35.00	28.34	27.82	27.41	27.22	28.03	29.40	31.09	32.79	34.76	36.84	39.07	41.43	43.83	46.39	49.23	52.47	55.89
37.50	28.09	27.58	27.19	26.91	28.13	29.47	31.15	32.86	34.84	36.89	39.11	41.46	43.91	46.51	49.34	52.62	56.12
40.00	27.93	27.44	27.02	27.04	28.30	29.67	31.31	33.00	35.03	37.08	39.28	41.62	44.09	46.73	49.60	52.87	56.43
42.50	27.81	27.27	26.84	27.18	28.46	29.78	31.53	33.27	35.27	37.28	39.54	41.86	44.33	46.96	49.89	53.22	56.81
45.00	27.81	27.25	26.80	27.44	28.67	30.05	31.82	33.59	35.63	37.63	39.88	42.17	44.64	47.31	50.28	53.65	57.32
47.50	27.96	27.28	26.89	27.83	29.10	30.49	32.29	34.08	36.13	38.15	40.39	42.67	45.16	47.80	50.82	54.25	57.98
50.00	28.07	27.33	27.02	28.08	29.33	30.77	32.58	34.43	36.53	38.53	40.74	43.03	45.53	48.22	51.26	54.73	58.53
52.50	28.27	27.47	27.35	28.36	29.59	31.16	33.02	34.93	37.07	39.07	41.34	43.55	46.07	48.79	51.86	55.38	59.26
55.00	28.52	27.60	27.80	28.72	30.00	31.66	33.56	35.54	37.71	39.72	41.89	44.19	46.70	49.47	52.57	56.14	60.11
57.50	28.88	27.92	28.38	29.26	30.56	32.30	34.25	36.30	38.50	40.48	42.65	44.97	47.49	50.29	53.46	57.05	61.12
60.00	29.31	28.33	29.07	29.87	31.21	33.03	35.00	37.17	39.42	41.43	43.57	45.87	48.42	51.29	54.47	57.14	62.33
62.50		29.26	29.67	30.52	32.04	33.90	35.96	38.18	40.49	42.49	44.63	46.92	49.49	52.40	55.72	59.41	
65.00			30.44	31.34	32.95	34.90	37.00	39.31	41.71	43.75	45.87	48.19	50.77	53.74	57.13		
67.50				32.34	34.00	36.00	38.21	40.60	43.12	45.17	47.30	49.66	52.24	55.33			
70.00					35.24	37.30	39.58	42.10	44.76	46.79	48.94	51.32	53.97				
72.50						38.74	41.16	43.81	46.63	48.68	50.85	53.28					
75.00						40.20	43.04	45.83	48.79	50.86	53.07	55.59					
77.50							45.25	48.18	51.34	53.36	55.62						
80.00							47.74	50.93	54.35	56.36	58.69						

Source: Winfrey (1969)

Table D.7: VOC at Varying Gradient for 5-kip Commercial Delivery Truck

Speed (mph)	Minus grade (%)								Level	Plus grade (%)							
	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
5.00	62.52	60.99	60.20	59.63	59.33	59.42	60.86	62.49	64.35	66.19	68.12	70.25	72.67	75.53	78.85	82.79	87.37
7.50	52.10	50.79	49.99	49.59	49.31	49.51	51.06	52.70	54.57	56.31	58.39	60.54	62.99	65.84	69.27	73.24	77.86
10.00	46.52	45.37	44.63	44.27	44.02	44.41	45.92	47.58	49.49	51.35	53.42	55.70	58.26	61.14	64.49	68.43	73.10
12.50	42.90	41.85	41.17	40.88	40.62	41.16	42.74	44.36	46.31	48.20	50.28	52.59	55.17	58.13	61.52	65.59	70.23
15.00	40.33	39.37	38.76	38.50	38.27	38.98	40.57	42.21	44.15	46.09	48.21	50.57	53.18	56.16	59.56	63.60	68.40
17.50	38.33	37.47	36.96	36.48	36.47	37.30	39.07	40.53	42.55	44.55	46.70	49.07	51.74	54.73	58.22	62.26	67.15
20.00	36.76	35.98	35.48	35.24	35.07	36.14	37.89	39.45	41.39	43.43	45.60	48.01	50.72	53.74	57.26	61.39	66.30
22.50	35.48	34.81	34.32	34.14	33.96	35.30	37.09	38.58	40.58	42.60	44.82	47.29	50.02	53.10	56.64	60.79	65.79
25.00	34.46	33.85	33.40	33.22	33.34	34.71	36.45	37.97	39.95	42.03	44.27	46.77	49.52	52.69	56.28	60.48	65.54
27.50	33.63	33.05	32.68	32.46	32.93	34.20	36.00	37.55	39.55	41.63	43.95	46.52	49.31	52.49	56.14	60.40	65.53
30.00	32.90	32.40	32.04	31.83	32.61	33.85	35.68	37.33	39.32	41.45	43.82	46.41	49.27	52.48	56.87	60.54	65.75
32.50	32.38	31.91	31.57	31.36	32.46	33.67	35.52	37.22	39.24	41.43	43.82	46.47	49.39	52.67	56.44	60.84	66.18
35.00	32.01	31.52	30.19	31.12	32.39	33.63	35.49	37.11	39.29	41.54	43.99	46.69	49.67	53.03	58.67	61.37	66.83
37.50	31.68	31.24	30.92	31.11	32.40	33.63	35.56	37.39	39.48	41.78	44.30	47.06	50.09	53.51	57.43	62.06	67.67
40.00	31.50	31.08	30.74	31.23	32.54	33.79	35.79	37.67	39.83	42.22	44.79	47.62	50.72	54.23	58.24	62.99	68.86
42.50	31.31	30.89	30.54	31.26	32.59	33.96	36.08	38.03	40.28	42.74	45.41	48.31	51.51	55.07	59.20	64.12	70.23
45.00	31.23	30.79	30.54	31.44	32.79	34.30	36.52	38.55	40.88	43.44	46.21	49.20	52.48	56.19	60.42	65.56	72.07
47.50	31.35	30.80	30.72	31.80	33.21	34.90	37.23	39.29	41.74	44.40	49.29	50.33	53.75	57.55	62.01	67.42	74.47
50.00	31.37	30.82	30.80	31.98	33.45	35.34	37.76	39.95	42.49	45.26	48.22	51.45	54.99	58.97	63.66	69.50	77.33
52.50		30.86	30.91	32.15	33.76	36.01	38.49	40.83	43.48	46.37	49.49	52.82	56.50	60.68	65.63	72.09	
55.00				32.49	34.28	36.82	39.37	41.93	44.72	47.74	50.98	54.48	58.34	62.74			
57.50				32.98	34.97	37.82	40.47	43.28	46.23	49.41	52.83	56.53	60.56	65.20			
60.00						38.97	41.77	44.88	48.11	51.46	55.09	59.01					
62.50							43.47	46.90	50.37	53.97	57.87						
65.00							45.57	49.37	53.10	56.94	61.58						
67.50								52.58	56.16	60.35							
70.00								56.51	59.70	64.28							

Source: Winfrey (1969)

Table D.8: VOC at Varying Gradient for 12-kip Single-Unit Truck

Speed (mph)	Minus grade (%)								Level	Plus grade (%)							
	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
5.00	87.65	87.38	87.10	86.83	86.72	89.29	92.23	95.68	99.08	102.19	105.48	109.09	113.09	117.59	122.73	128.65	135.66
7.50	73.37	72.79	72.71	72.40	72.69	75.23	78.27	81.42	85.35	88.60	91.97	95.79	99.94	104.63	110.01	116.21	123.72
10.00	65.31	64.97	64.58	64.20	64.78	67.19	70.27	73.51	77.68	81.04	84.59	88.56	92.94	97.86	103.43	109.97	118.06
12.50	60.31	59.85	59.36	58.90	59.81	61.97	65.06	68.37	72.86	76.33	80.03	84.27	88.86	94.08	100.00	106.95	115.67
15.00	56.81	56.27	55.68	55.14	56.27	58.39	61.35	64.89	69.62	73.25	77.14	81.66	86.51	92.04	98.41	106.01	115.71
17.50	54.32	53.71	53.00	52.51	53.89	55.88	58.81	62.38	67.37	71.22	75.32	80.12	85.34	91.26	98.31	106.86	117.87
20.00	52.55	51.84	51.08	50.89	52.21	53.95	56.94	60.74	65.90	69.96	74.30	79.43	85.14	91.64	99.57	109.65	122.13
22.50	51.46	50.64	49.77	49.97	51.21	52.88	55.98	59.72	65.09	69.40	73.98	79.53	85.80	93.21	102.24	114.65	128.44
25.00	50.69	49.77	48.88	49.46	50.63	51.33	55.03	59.22	64.73	69.33	74.21	80.32	97.18	96.09	106.11	121.91	
27.50		49.40	48.77	49.30	50.57	52.21	54.74	59.08	64.76	69.68	74.93	81.49	89.30	100.26	110.70		
30.00		49.15	48.76	49.27	50.53	52.21	54.68	59.30	65.11	70.42	76.02	83.17	92.03	104.56	115.81		
32.50		49.33	49.14	49.58	50.89	52.62	55.08	59.85	64.75	71.46	77.54	85.28	95.48	109.68	121.79		
35.00		50.53	50.04	50.30	51.54	53.26	55.76	60.59	66.60	72.77	79.37	87.81	99.74	115.66			
37.50			51.23	51.44	52.50	54.10	56.67	61.57	67.66	74.28	81.50	90.66	104.93	122.13			
40.00			53.30	52.82	53.62	55.10	57.81	62.71	68.87	76.09	83.95	93.86	110.86				
42.50				54.20	54.72	56.09	59.21	64.06	70.27	78.10	86.68	97.44	117.84				
45.00					56.11	57.45	60.80	65.48	71.84	80.35	89.65	101.32					
47.50						59.08	62.60	67.18	73.60	82.95	92.84	105.53					
50.00						60.94	64.64	68.99	75.59	85.74	96.27	110.14					
52.50						63.15	66.91	70.95	77.79	88.66	100.04						
55.00						65.57	69.43	73.08	80.24	91.67	104.10						
57.50							72.12	75.34	82.86	94.83							
60.00							75.06	77.77	85.84	98.17							
62.50							78.31	80.43	89.05	101.73							
65.00								83.31	92.57	105.52							

Source: Winfrey (1969)

Table D.9: VOC at Varying Gradient for 40-kip 2-S2 Heavy Truck (Gasoline)

Speed (mph)	Minus grade (%)								Level	Plus grade (%)							
	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
5.00	218.35	212.50	206.65	201.96	194.63	193.37	203.19	212.25	231.01	236.70	243.35	251.86	262.26	275.01	292.53	318.11	357.71
7.50	160.37	157.37	152.36	147.45	140.55	139.07	148.67	157.79	176.66	183.28	190.90	199.97	210.83	224.53	242.12	267.64	308.99
10.00	132.45	128.83	123.33	118.95	112.70	110.94	120.13	129.37	148.64	155.92	164.41	174.24	185.97	200.79	219.37	245.80	289.90
12.50	112.38	111.47	106.52	101.46	95.83	93.80	102.54	111.91	131.48	139.55	148.83	159.79	172.84	189.05	209.61	238.76	285.44
15.00	102.35	100.33	95.03	89.79	85.01	82.80	90.87	100.38	120.17	129.22	139.29	151.65	166.46	184.53	208.39	242.57	
17.50		92.96	87.14	81.99	77.84	76.73	82.84	92.55	112.43	122.53	133.52	147.49	164.58	185.44	214.08	256.24	
20.00			81.70	76.70	73.19	71.01	77.31	87.17	107.10	118.37	130.38	146.21	166.24	191.29	226.44		
22.50			77.70	73.72	70.38	68.55	73.90	83.54	103.47	116.01	129.23	147.16	170.80	202.54	245.49		
25.00			75.64	71.00	68.87	68.00	71.20	81.30	101.19	115.20	129.79	150.02	178.14	220.81			
27.50				69.89	68.59	67.93	69.94	80.02	99.93	115.53	131.71	154.45	187.84	245.27			
30.00				69.78	68.97	68.89	69.61	79.90	99.51	116.87	134.92	160.45	199.87				
32.50					69.68	68.89	70.10	80.60	99.87	119.16	139.38	167.79	214.91				
35.00						69.80	71.31	81.98	100.84	122.25	145.06	176.70					
37.50						70.97	73.17	83.92	102.43	126.18	152.02	186.36					
40.00						72.36	75.55	86.38	104.55	130.98	160.32	198.21					
42.50						74.03	78.48	89.25	107.21	136.72	169.77						
45.00						75.97	81.99	92.47	110.43	143.65	180.56						
47.50							86.01	96.23	114.23	152.40	192.73						
50.00							90.48	100.24	118.70	161.98	206.39						
52.50							95.30	104.57	123.98	172.36							
55.00							100.47	109.22	130.33	183.49							
57.50								114.18	137.35	195.50							
60.00								119.38	145.55								

Source: Winfrey (1969)

Table D.10: VOC at Varying Gradient for 50-kip 3-S2 Heavy Truck (Diesel)

Speed (mph)	Minus grade (%)								Level	Plus grade (%)							
	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
5.00	161.84	158.90	156.00	153.69	150.13	149.42	153.82	157.86	166.72	171.45	176.40	181.21	186.01	190.64	195.25	199.85	205.37
7.50	129.98	128.21	125.53	122.96	119.46	118.56	122.96	127.08	136.35	144.82	153.22	161.46	169.51	177.45	185.29	193.02	201.65
10.00	113.96	111.78	109.07	106.30	102.95	101.83	106.17	110.50	120.20	130.60	140.90	151.05	161.04	170.93	180.66	190.69	201.65
12.50	102.37	101.46	98.57	95.67	92.51	91.23	95.41	99.95	110.11	121.74	133.34	144.83	156.24	167.63	178.65	190.97	203.83
15.00	96.27	94.76	91.51	88.38	85.54	84.07	88.05	92.76	103.41	115.97	128.51	141.17	153.86	166.66	179.36	193.66	208.54
17.50		89.71	86.10	82.84	80.28	79.32	82.35	87.79	98.84	112.17	125.54	139.24	153.22	167.54	182.22	198.84	214.81
20.00			82.64	79.37	77.04	75.47	78.65	84.36	95.81	109.81	123.95	138.70	154.07	170.17	187.30	207.02	223.23
22.50			80.35	77.59	75.03	73.59	76.44	82.10	93.89	108.54	123.45	139.28	156.21	174.65	194.76	218.71	
25.00			79.03	75.70	73.98	72.73	74.57	80.79	92.92	108.27	123.94	140.91	159.75	181.46	204.95		
27.50				75.06	73.78	72.43	73.76	80.18	92.64	108.64	125.17	143.38	164.46	190.43			
30.00				75.11	73.64	72.73	73.58	80.38	93.02	109.75	127.14	146.79	170.57				
32.50					74.42	73.41	74.27	81.27	94.00	111.48	129.89	151.20	178.03				
35.00						74.40	75.48	82.75	95.51	113.76	133.34	156.46	187.58				
37.50						75.70	77.25	84.69	97.49	116.55	137.43	162.56					
40.00						77.29	79.47	87.07	99.85	119.87	142.28	169.96					
42.50						79.37	82.11	89.79	102.61	123.57	147.63						
45.00						81.83	85.20	92.77	105.80	127.88	153.72						
47.50							88.69	96.25	109.45	132.97	160.68						
50.00							92.76	100.04	113.63	138.77							
52.50							97.19	104.11	118.37	145.20							
55.00							101.92	108.32	123.66	152.23							
57.50								112.98	129.12	160.20							
60.00									134.60								

Source: Winfrey (1969)

Table D.11: Additional VOC at Horizontal Curves for 4-kip Passenger Car

Speed (mph)	Degree of horizontal curve														
	1	2	3	4	5	6	8	10	12	14	16	18	20	25	30
5	0.44	0.84	1.15	1.40	1.60	1.76	2.12	2.46	2.82	3.20	3.58	3.98	4.40	5.50	6.82
10	0.71	1.36	1.89	2.31	2.69	3.06	3.71	4.40	5.08	5.78	6.50	7.24	7.99	9.94	12.30
15	0.88	1.69	2.33	2.87	3.47	3.83	4.95	6.08	7.30	8.50	9.80	11.00	12.90	16.40	21.04
20	0.90	1.70	2.46	3.20	3.91	4.60	6.00	7.60	9.20	10.97	12.90	15.00	17.40	24.70	35.10
25	0.92	1.78	2.61	3.45	4.33	5.25	7.24	9.54	12.12	15.00	18.27	21.88	25.80	38.10	54.20
30	0.96	1.89	2.97	3.89	5.04	6.32	9.08	12.43	16.88	22.00	27.70	33.80	40.30	57.90	78.10
35	1.06	2.20	3.64	4.81	6.87	8.28	11.80	17.13	23.90	31.45	39.60	48.30	57.40	80.70	
40	1.39	2.84	4.75	6.47	9.00	11.34	17.70	25.40	34.06	43.50	53.60	64.10	75.40		
45	1.88	3.88	6.38	8.70	12.18	15.60	25.50	35.20	46.50	58.90	71.80				
50	2.55	5.35	8.59	11.89	16.50	21.00	33.42	46.00	59.72	74.10					
55	3.48	7.23	11.49	16.02	22.04	27.95	42.40	57.40	74.30						
60	4.68	9.71	15.25	21.26	28.89	36.31	53.40	71.80							
65	6.16	12.73	19.96	27.76	37.14	46.39	66.50	89.00							
70	7.85	16.35	25.78	35.76	46.99	58.44	82.49								
75	10.20	21.20	32.99	45.54	58.82	72.79									
80	13.20	27.45	42.49	58.30	74.84										

Source: Winfrey (1969)

Table D.12: Additional VOC at Horizontal Curves for 5-kip Commercial Delivery Truck

Speed (mph)	Degree of horizontal curve														
	1	2	3	4	5	6	8	10	12	14	16	18	20	25	30
5	0.56	1.00	1.33	1.60	1.80	1.98	2.38	2.81	3.30	3.75	4.18	4.62	5.08	6.34	7.92
10	0.91	1.69	2.21	2.63	2.98	3.31	4.12	5.05	6.05	7.01	8.00	9.00	9.95	12.25	14.48
15	1.08	2.00	2.70	3.25	3.84	4.60	6.00	7.40	8.70	10.00	11.40	12.80	14.40	19.00	25.00
20	1.14	2.04	2.54	3.74	4.74	5.64	7.60	9.30	11.16	13.05	15.00	17.21	19.86	27.70	39.40
25	1.17	1.97	2.97	4.22	5.27	6.29	8.68	11.32	14.16	17.18	20.39	23.91	27.83	39.80	58.50
30	1.28	2.38	3.78	5.08	6.31	7.68	10.87	14.61	18.88	23.66	28.92	34.63	40.78	61.80	94.20
35	1.52	3.02	4.82	6.70	8.53	10.56	15.27	20.78	27.12	34.21	42.16	51.07	61.82	99.20	
40	1.89	3.82	6.04	8.55	11.36	14.47	21.59	29.90	39.40	50.10	64.20	83.80			
45	2.45	5.14	8.23	11.73	15.86	20.51	30.11	41.40	54.54	70.40	93.40				
50	3.20	6.27	10.10	14.66	19.93	25.85	39.57	55.53	76.50	91.00					
55	4.19	8.90	14.00	19.90	26.57	33.97	51.08	74.30							
60	5.50	11.86	18.68	26.12	34.39	43.80	68.40								
65	7.29	15.30	24.00	33.63	44.51	57.21	93.90								
70	9.79	20.38	31.68	43.99	57.71	73.69									

Source: Winfrey (1969)

Table D.13: Additional VOC at Horizontal Curves for 12-kip Single-Unit Truck

Speed (mph)	Degree of horizontal curve														
	1	2	3	4	5	6	8	10	12	14	16	18	20	25	30
5	1.09	2.04	2.83	3.45	3.87	4.19	4.89	5.99	7.04	8.06	9.09	10.07	11.05	13.34	15.35
10	1.96	3.59	4.89	5.88	6.47	6.99	9.10	11.15	13.24	15.29	17.32	19.38	20.89	26.25	31.04
15	2.42	4.40	5.84	6.87	8.41	9.90	12.95	15.96	19.07	22.23	25.42	28.67	31.95	40.43	55.47
20	2.34	4.19	6.21	8.21	10.21	12.05	15.88	19.75	23.79	27.95	32.54	37.13	41.93	59.91	82.08
25	2.40	4.25	7.05	9.33	11.68	13.84	18.43	23.24	28.45	34.75	45.40	56.54	68.06	100.20	148.50
30	2.50	5.25	7.82	10.35	13.03	15.51	20.92	28.72	42.73	57.46	72.84	88.90	105.86		
35	2.74	5.52	8.26	11.04	14.00	17.60	30.46	46.16	64.98	84.69	105.43	127.38			
40	2.88	5.88	10.24	15.57	22.05	29.31	46.82	67.67	92.13	118.07	145.53				
45	4.53	10.06	16.60	24.21	33.05	42.88	65.76	92.60	123.70						
50	6.84	14.85	23.90	34.14	45.75	58.43	87.78	121.78							
55	9.61	20.39	32.49	41.72	60.71	77.05									
60	12.75	26.83	42.33												
65	16.45	34.28	54.03												

Source: Winfrey (1969)

Table D.14: Additional VOC at Horizontal Curves for 40-kip 2-S2 Heavy Truck (Gasoline)

Speed (mph)	Degree of horizontal curve														
	1	2	3	4	5	6	8	10	12	14	16	18	20	25	30
5	2.32	4.58	6.63	7.48	9.87	11.02	13.39	16.00	18.19	20.32	22.46	24.55	26.69	31.56	36.10
10	3.95	7.29	10.42	12.74	14.35	13.73	20.47	24.80	29.15	32.96	36.98	41.02	45.25	54.64	64.80
15	4.91	8.95	12.07	14.33	17.61	20.75	27.09	33.20	39.31	45.49	51.70	58.05	64.46	81.08	99.00
20	4.73	8.50	12.69	16.79	20.95	24.74	32.53	40.31	48.77	56.59	65.78	94.96	84.56	121.08	166.02
25	4.88	8.71	14.44	19.17	23.97	28.39	37.79	47.55	58.21	70.88	92.83	115.65	139.42	207.09	281.62
30	5.15	10.85	16.19	21.39	26.95	32.15	43.40	59.59	88.60	119.34	151.45	185.15	220.77		
35	5.78	11.67	17.47	23.34	29.58	37.32	64.55	97.80	137.85	180.01	224.66	272.09			
40	6.23	12.84	22.30	33.87	48.03	63.81	102.12	147.91	202.00	259.90	321.74				
45	10.12	22.56	37.28	54.32	74.30	96.38	148.27	209.75	281.61						
50	15.82	34.31	55.41	79.24	106.36	136.15	205.70	287.60							
55	23.01	48.85	78.09	100.77	146.78	186.70									
60	31.59	66.53	105.47												

Source: Winfrey (1969)

Table D.15: Additional VOC at Horizontal Curves for 50-kip 3-S2 Heavy Truck (Diesel)

Speed (mph)	Degree of horizontal curve														
	1	2	3	4	5	6	8	10	12	14	16	18	20	25	30
5	2.96	5.66	7.89	9.77	11.09	12.09	14.24	17.40	20.77	23.06	25.83	28.54	31.19	37.51	43.13
10	5.21	9.59	13.14	15.80	17.47	18.93	24.66	30.14	35.72	41.11	46.51	51.89	57.56	70.16	85.30
15	6.50	11.66	15.57	18.22	22.36	26.31	34.40	42.45	50.73	59.10	67.50	76.11	84.77	107.17	135.00
20	6.22	11.12	16.54	21.78	27.11	32.05	42.23	52.57	63.80	74.43	86.67	98.85	111.56	159.51	218.45
25	6.47	11.45	19.05	25.12	31.43	37.24	49.63	62.59	76.70	93.42	122.33	152.29	183.38	269.73	366.72
30	6.78	14.26	21.28	28.11	35.42	42.23	56.99	78.22	116.30	156.43	198.62	241.72	287.62		
35	7.59	15.31	22.90	30.57	38.69	48.81	84.47	127.85	179.74	233.97	290.93	351.01			
40	8.15	16.75	29.10	44.22	62.67	83.23	132.89	191.78	260.63	333.29	410.07				
45	13.19	29.41	48.45	70.69	96.59	125.00	191.30	268.84	357.94						
50	20.59	44.59	71.88	102.55	137.22	174.94	261.74	361.67							
55	29.92	63.31	100.63	129.09	187.52	237.06									
60	40.96	85.63	135.04												

Source: Winfrey (1969)

Table D.16: Conversion Factor to Convert Running Cost of Vehicle on Paved-to-Gravel Roadway Surfaces

Speed (mph)	**Passenger car** 4-kip	**Commercial delivery** 5-kip	**Single-unit truck** 12-kip	**Heavy truck 2-S2 (gasoline)** 40-kip	**Heavy truck 3-S2 (diesel)** 50-kip
5.00	1.079	1.074	1.090	1.114	1.129
7.50	1.106	1.100	1.122	1.148	1.172
10.00	1.132	1.125	1.152	1.181	1.210
12.50	1.157	1.149	1.180	1.212	1.245
15.00	1.181	1.172	1.207	1.241	1.278
17.50	1.205	1.193	1.232	1.267	1.307
20.00	1.228	1.215	1.256	1.291	1.334
22.50	1.250	1.237	1.279	1.314	1.359
25.00	1.272	1.259	1.300	1.336	1.382
27.50	1.294	1.281	1.321	1.357	1.404
30.00	1.315	1.302	1.341	1.377	1.424
32.50	1.337	1.323	1.361	1.397	1.444
35.00	1.358	1.344	1.381	1.417	1.464
37.50	1.380	1.365	1.401	1.437	1.483
40.00	1.402	1.387	1.421	1.457	1.501
42.50	1.424	1.409	1.441	1.476	1.518
45.00	1.447	1.431	1.462	1.495	1.535
47.50	1.471	1.455	1.484	1.515	1.553
50.00	1.498	1.479	1.507	1.536	1.572
52.50	1.526	1.504	1.531	1.557	1.592
55.00	1.557	1.531	1.557	1.579	1.614
57.50	1.592	1.561			
60.00	1.631	1.592			

Source: Winfrey (1969)

Appendix E: Safety Calculations and Tables

This appendix shows average AADT on gravel roads and paved roads for 56 counties that responded to the survey questionnaire with traffic volume details in Table E.1. Table E.1 also shows mileage of gravel roads and paved roads for the 56 counties and calculated VMT. Table E.2 shows the types of crashes on gravel roads and paved roads in the 56 counties during the years 2010–2014. Table E.3 shows crash rates of various types of crashes, and Table E.4 shows total EPDO crashes and EPDO crash rates.

Table E.1: VMT on Paved and Gravel Roads for 56 Counties with Traffic Volume Details

No.	County	Paved road			Gravel road		
		AADT	Miles	VMT in 5 years ($\times 10^8$)	AADT	Miles	VMT in 5 years ($\times 10^8$)
1	Allen	1650	183	5.511	260	817	3.877
2	Atchison	510	116	1.080	102.5	173	0.324
3	Barber	67.5	153	0.188	67.5	101	0.124
4	Chase	290	42	0.222	50.5	440	0.406
5	Cheyenne	325	12	0.071	130	789	1.872
6	Clark	110	7	0.014	65	572	0.679
7	Clay	1050	175	3.353	175	508	1.622
8	Coffey	450	228	1.872	110	962	1.931
9	Comanche	50	22	0.020	17.5	578	0.185
10	Doniphan	425	70	0.543	160	394	1.150
11	Douglas	2025	173	6.393	125	34	0.078
12	Ellis	1875	141	4.825	240	1,139	4.989
13	Ford	727.5	228	3.027	95	162	0.281
14	Franklin	1089.5	206	4.096	95	823	1.427
15	Grant	100	170	0.310	100	635	1.159
16	Greeley	425	4	0.031	105	600	1.150
17	Greenwood	50	36	0.033	50	397	0.362
18	Jackson	75	63	0.086	52.5	754	0.722
19	Jefferson	1323	149	3.598	137.5	673	1.689
20	Jewell	175	29	0.093	125	696	1.588
21	Johnson	2350	277	11.880	210	155	0.594
22	Kearny	115	100	0.210	30	652	0.357
23	Kingman	275	249	1.250	55	5	0.005
24	Kiowa	172.5	83	0.261	66	399	0.481
25	Labette	300	163	0.892	125	971	2.215
26	Lane	447.5	1	0.008	327.5	451	2.696
27	Leavenworth	2125	269	10.432	162.5	460	1.364
28	Lincoln	275	37	0.186	115	563	1.182
29	Lyon	1700	122	3.785	135	1,046	2.577
30	Marion	500	132	1.205	275	746	3.744
31	McPherson	912.5	293	4.879	230	54	0.227
32	Meade	115	94	0.197	80	153	0.223
33	Miami	3150	476	27.364	120	850	1.862
34	Mitchell	277.5	130	0.658	66.5	128	0.155
35	Montgomery	1300	317	7.521	105	701	1.343
36	Morris	300	99	0.542	140	979	2.501
37	Morton	225	123	0.505	75	435	0.595
38	Osage	200	85	0.310	100	164	0.299

39	Osborne	530	9	0.087	163	221	0.657
40	Ottawa	925	85	1.435	101	587	1.082
41	Pawnee	342.5	75	0.469	162.5	186	0.552
42	Pottawatomie	3800	184	12.760	337.5	819	5.045
43	Republic	125	82	0.187	51.5	701	0.659
44	Rice	1270	159	3.685	620	157	1.776
45	Riley	2550	124	5.771	55	109	0.109
46	Rooks	175	45	0.144	100	859	1.568
47	Sedgwick	1775	558	18.076	252.5	42	0.194
48	Stafford	392.5	211	1.511	65	39	0.046
49	Stanton	57.5	105	0.110	20	536	0.196
50	Stevens	362.5	148	0.979	250	786	3.586
51	Sumner	1825	172	5.729	207.5	223	0.844
52	Thomas	125	118	0.269	82.5	114	0.172
53	Wallace	117.5	17	0.036	100	553	1.009
54	Washington	350	60	0.383	145	240	0.635
55	Wichita	125	15	0.034	100	650	1.186
56	Wilson	75	125	0.171	16	1,075	0.314

Table E.2: Types of Crashes on Paved and Gravel Roads

No.	County	Paved				Gravel			
		PDO crash	Injury crash	Fatal crash	Total crashes	PDO crash	Injury crash	Fatal crash	Total crashes
1	Allen	0	28	2	152	65	20	2	87
2	Atchison	54	13	2	69	73	8	1	82
3	Barber	20	4	1	25	16	4	0	20
4	Chase	12	1	0	13	10	1	1	12
5	Cheyenne	17	2	0	19	14	11	0	25
6	Clark	35	4	0	39	16	9	0	25
7	Clay	148	22	0	170	48	12	3	63
8	Coffey	201	28	1	230	62	21	0	83
9	Comanche	4	1	1	6	3	1	0	4
10	Doniphan	44	11	1	56	35	7	2	44
11	Douglas	351	94	3	448	168	67	3	238
12	Ellis	93	25	1	119	101	66	7	174
13	Ford	48	16	2	66	29	9	1	39
14	Franklin	69	15	1	85	124	35	5	164
15	Grant	18	14	0	32	10	11	1	22
16	Greeley	11	2	0	13	8	5	1	14
17	Greenwood	67	11	1	79	37	17	1	55
18	Jackson	62	9	1	72	107	53	4	164
19	Jefferson	126	32	3	161	122	39	1	162
20	Jewell	8	0	0	8	37	5	0	42
21	Johnson	316	106	0	422	49	23	0	72
22	Kearny	76	24	1	101	18	7	1	26
23	Kingman	61	11	0	72	23	6	0	29
24	Kiowa	29	10	0	39	22	6	3	31
25	Labette	104	36	6	146	112	43	5	160
26	Lane	11	1	0	12	6	3	0	9
27	Leavenworth	285	90	3	378	158	52	1	211
28	Lincoln	25	6	0	31	49	20	0	69
29	Lyon	62	12	0	74	105	24	2	131
30	Marion	133	17	0	150	63	25	0	88
31	McPherson	120	33	0	153	128	77	2	207
32	Meade	32	5	1	38	16	3	0	19
33	Miami	292	84	7	383	203	64	2	269
34	Mitchell	136	17	0	153	40	10	0	50
35	Montgomery	193	57	5	255	103	39	1	143
36	Morris	43	6	0	49	51	14	1	66
37	Morton	59	7	0	66	1	1	1	3
38	Osage	68	10	0	78	94	55	3	152
39	Osborne	29	2	0	31	20	8	0	28
40	Ottawa	83	7	0	90	53	14	0	67

41	Pawnee	111	26	0	137	54	18	2	74
42	Pottawatomie	139	34	0	173	139	69	2	210
43	Republic	86	6	0	92	24	5	1	30
44	Rice	84	9	1	94	41	13	2	56
45	Riley	99	34	0	133	45	29	0	74
46	Rooks	84	7	1	92	71	14	2	87
47	Sedgwick	949	328	6	1283	146	103	4	253
48	Stafford	66	8	0	74	31	1	0	32
49	Stanton	15	4	0	19	11	1	0	12
50	Stevens	76	15	3	94	12	3	1	16
51	Sumner	77	23	0	100	80	34	2	116
52	Thomas	17	6	0	23	25	6	0	31
53	Wallace	3	1	0	4	8	1	0	9
54	Washington	62	7	0	69	101	15	2	118
55	Wichita	32	2	0	34	13	8	3	24
56	Wilson	149	29	1	179	59	17	0	76
	Total	**5594**	**1412**	**55**	**7183**	**3259**	**1232**	**76**	**4567**

Table E.3: Number of Types of Crashes per VMT on Paved and Gravel Roads

No.	County	Crashes per 10^8 VMT on paved roads				Crashes per 10^8 VMT on gravel roads			
		PDO	Injury	Fatal	Total	PDO	Injury	Fatal	Total
1	Allen	22.14	5.08	0.36	27.58	16.77	5.16	0.52	22.44
2	Atchison	50.02	12.04	1.85	63.91	225.57	24.72	3.09	253.39
3	Barber	106.11	21.22	5.31	132.64	128.60	32.15	0.00	160.75
4	Chase	53.98	4.50	0.00	58.48	24.66	2.47	2.47	29.59
5	Cheyenne	238.85	28.10	0.00	266.95	7.48	5.88	0.00	13.36
6	Clark	2490.66	284.65	0.00	2775.31	23.58	13.26	0.00	36.84
7	Clay	44.13	6.56	0.00	50.69	29.59	7.40	1.85	38.83
8	Coffey	107.35	14.95	0.53	122.83	32.10	10.87	0.00	42.98
9	Comanche	199.25	49.81	49.81	298.88	16.25	5.42	0.00	21.67
10	Doniphan	81.04	20.26	1.84	103.14	30.42	6.08	1.74	38.24
11	Douglas	54.90	14.70	0.47	70.07	2166.00	863.82	38.68	3068.49
12	Ellis	19.28	5.18	0.21	24.66	20.25	13.23	1.40	34.88
13	Ford	15.86	5.29	0.66	21.80	103.25	32.04	3.56	138.86
14	Franklin	16.85	3.66	0.24	20.75	86.90	24.53	3.50	114.94
15	Grant	58.02	45.12	0.00	103.14	8.63	9.49	0.86	18.98
16	Greeley	354.55	64.46	0.00	419.02	6.96	4.35	0.87	12.18
17	Greenwood	2039.57	334.86	30.44	2404.87	102.14	46.93	2.76	151.82
18	Jackson	719.00	104.37	11.60	834.96	148.11	73.36	5.54	227.01
19	Jefferson	35.02	8.89	0.83	44.75	72.24	23.09	0.59	95.93
20	Jewell	86.38	0.00	0.00	86.38	23.30	3.15	0.00	26.45
21	Johnson	26.60	8.92	0.00	35.52	82.49	38.72	0.00	121.20
22	Kearny	362.12	114.35	4.76	481.24	50.42	19.61	2.80	72.84
23	Kingman	48.81	8.80	0.00	57.62	4582.81	1195.52	0.00	5778.33
24	Kiowa	110.99	38.27	0.00	149.26	45.78	12.48	6.24	64.50
25	Labette	116.54	40.34	6.72	163.60	50.56	19.41	2.26	72.23
26	Lane	1346.90	122.45	0.00	1469.35	2.23	1.11	0.00	3.34
27	Leavenworth	27.32	8.63	0.29	36.23	115.82	38.12	0.73	154.67
28	Lincoln	134.63	32.31	0.00	166.94	41.47	16.93	0.00	58.40
29	Lyon	16.38	3.17	0.00	19.55	40.74	9.31	0.78	50.83
30	Marion	110.42	14.11	0.00	124.53	16.83	6.68	0.00	23.50
31	McPherson	24.59	6.76	0.00	31.36	564.71	339.71	8.82	913.24
32	Meade	162.20	25.34	5.07	192.62	71.63	13.43	0.00	85.06
33	Miami	10.67	3.07	0.26	14.00	109.05	34.38	1.07	144.51
34	Mitchell	206.57	25.82	0.00	232.39	257.49	64.37	0.00	321.87
35	Montgomery	25.66	7.58	0.66	33.91	76.68	29.03	0.74	106.45
36	Morris	79.33	11.07	0.00	90.40	20.39	5.60	0.40	26.39
37	Morton	116.82	13.86	0.00	130.68	1.68	1.68	1.68	5.04
38	Osage	219.18	32.23	0.00	251.41	314.07	183.76	10.02	507.85

39	Osborne	333.13	22.97	0.00	356.11	30.42	12.17	0.00	42.59
40	Ottawa	57.84	4.88	0.00	62.72	48.98	12.94	0.00	61.92
41	Pawnee	236.78	55.46	0.00	292.24	97.90	32.63	3.63	134.15
42	Pottawatomie	10.89	2.66	0.00	13.56	27.55	13.68	0.40	41.63
43	Republic	459.74	32.07	0.00	491.81	36.43	7.59	1.52	45.53
44	Rice	22.79	2.44	0.27	25.51	23.08	7.32	1.13	31.52
45	Riley	17.16	5.89	0.00	23.05	411.30	265.06	0.00	676.36
46	Rooks	584.47	48.71	6.96	640.14	45.29	8.93	1.28	55.50
47	Sedgwick	52.50	18.15	0.33	70.98	754.36	532.19	20.67	1307.21
48	Stafford	43.67	5.29	0.00	48.96	670.07	21.62	0.00	691.69
49	Stanton	136.14	36.30	0.00	172.44	56.23	5.11	0.00	61.34
50	Stevens	77.62	15.32	3.06	96.01	3.35	0.84	0.28	4.46
51	Sumner	13.44	4.01	0.00	17.46	94.73	40.26	2.37	137.36
52	Thomas	63.15	22.29	0.00	85.44	145.65	34.96	0.00	180.61
53	Wallace	82.29	27.43	0.00	109.73	7.93	0.99	0.00	8.92
54	Washington	161.77	18.26	0.00	180.04	159.03	23.62	3.15	185.80
55	Wichita	935.16	58.45	0.00	993.61	379.91	6.74	2.53	20.23
56	Wilson	870.87	169.50	5.84	1046.21	344.84	54.16	0.00	242.12
	Average	**251.75**	**37.52**	**2.47**	**291.74**	**233.12**	**77.11**	**2.50**	**303.34**

Table E.4: Comparison of Paved and Gravel EPDO Crashes and EPDO Crash Rates

No.	County	EPDO crashes		EPDO crashes per 10^8 VMT	
		Paved	Gravel	Paved	Gravel
1	Allen	450	395	103.80	101.89
2	Atchison	279	208	258.41	642.73
3	Barber	95	76	504.04	610.84
4	Chase	27	40	121.47	98.64
5	Cheyenne	47	179	660.34	95.62
6	Clark	95	151	6760.36	222.54
7	Clay	478	273	142.54	168.27
8	Coffey	636	377	339.66	195.21
9	Comanche	34	18	1693.65	97.51
10	Doniphan	224	170	412.57	147.76
11	Douglas	1806	1218	282.48	15703.46
12	Ellis	483	1196	100.11	239.74
13	Ford	318	179	105.05	637.31
14	Franklin	309	724	75.44	507.40
15	Grant	228	190	734.89	163.95
16	Greeley	41	98	1321.51	85.24
17	Greenwood	247	307	7519.03	847.45
18	Jackson	212	962	2458.51	1331.62
19	Jefferson	651	722	180.96	427.52
20	Jewell	8	112	86.38	70.54
21	Johnson	1906	394	160.44	663.26
22	Kearny	451	138	2148.90	386.59
23	Kingman	226	113	180.85	22515.57
24	Kiowa	179	157	685.05	326.68
25	Labette	734	832	822.48	375.60
26	Lane	26	51	3183.59	18.92
27	Leavenworth	1680	953	161.04	698.58
28	Lincoln	115	349	619.30	295.36
29	Lyon	242	495	63.94	192.08
30	Marion	388	438	322.13	116.99
31	McPherson	615	1313	126.04	5792.69
32	Meade	122	61	618.40	273.08
33	Miami	1657	1193	60.55	640.88
34	Mitchell	391	190	593.89	1223.09
35	Montgomery	1123	703	149.32	523.34
36	Morris	133	276	245.38	110.34
37	Morton	164	31	324.71	52.07
38	Osage	218	964	702.66	3220.85

39	Osborne	59	140	677.75	212.95
40	Ottawa	188	263	131.02	243.07
41	Pawnee	501	354	1068.69	641.76
42	Pottawatomie	649	1204	50.86	238.67
43	Republic	176	114	940.86	173.03
44	Rice	234	266	63.50	149.74
45	Riley	609	480	105.53	4387.22
46	Rooks	204	311	1419.44	198.38
47	Sedgwick	5959	1751	329.67	9047.17
48	Stafford	186	46	123.06	994.30
49	Stanton	75	26	680.68	132.90
50	Stevens	346	72	353.38	20.08
51	Sumner	422	620	73.66	734.19
52	Thomas	107	115	397.49	670.00
53	Wallace	18	23	493.77	22.79
54	Washington	167	356	435.75	560.54
55	Wichita	62	178	1811.87	519.00
56	Wilson	599	314	3501.00	1157.20
	Average	**493**	**409**	**851.57**	**1427.22**

Appendix F: Screenshots of the Gravel Road Paving Guidelines Program

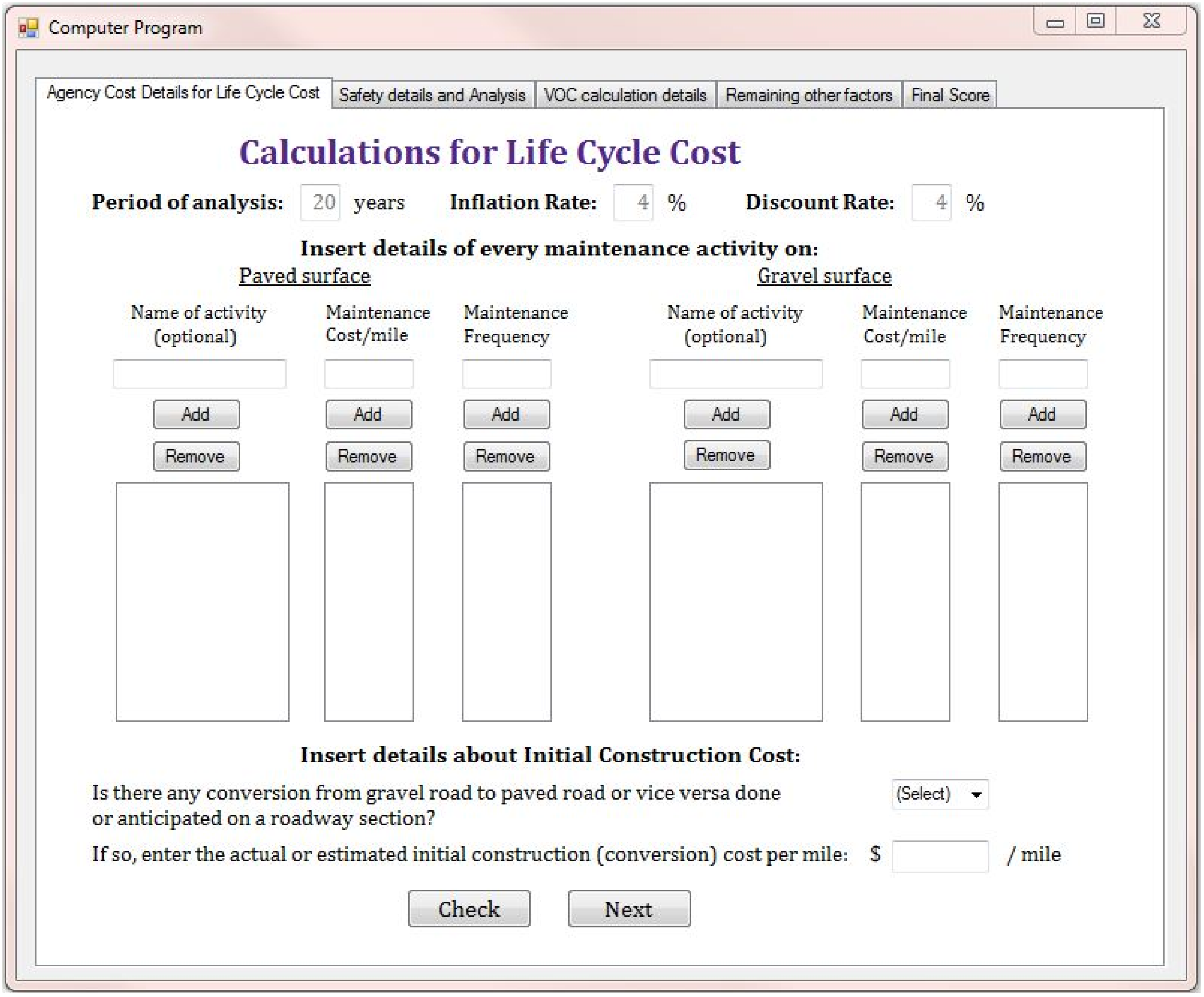

Figure F.1: User Input Layout for Calculating Life Cycle Cost

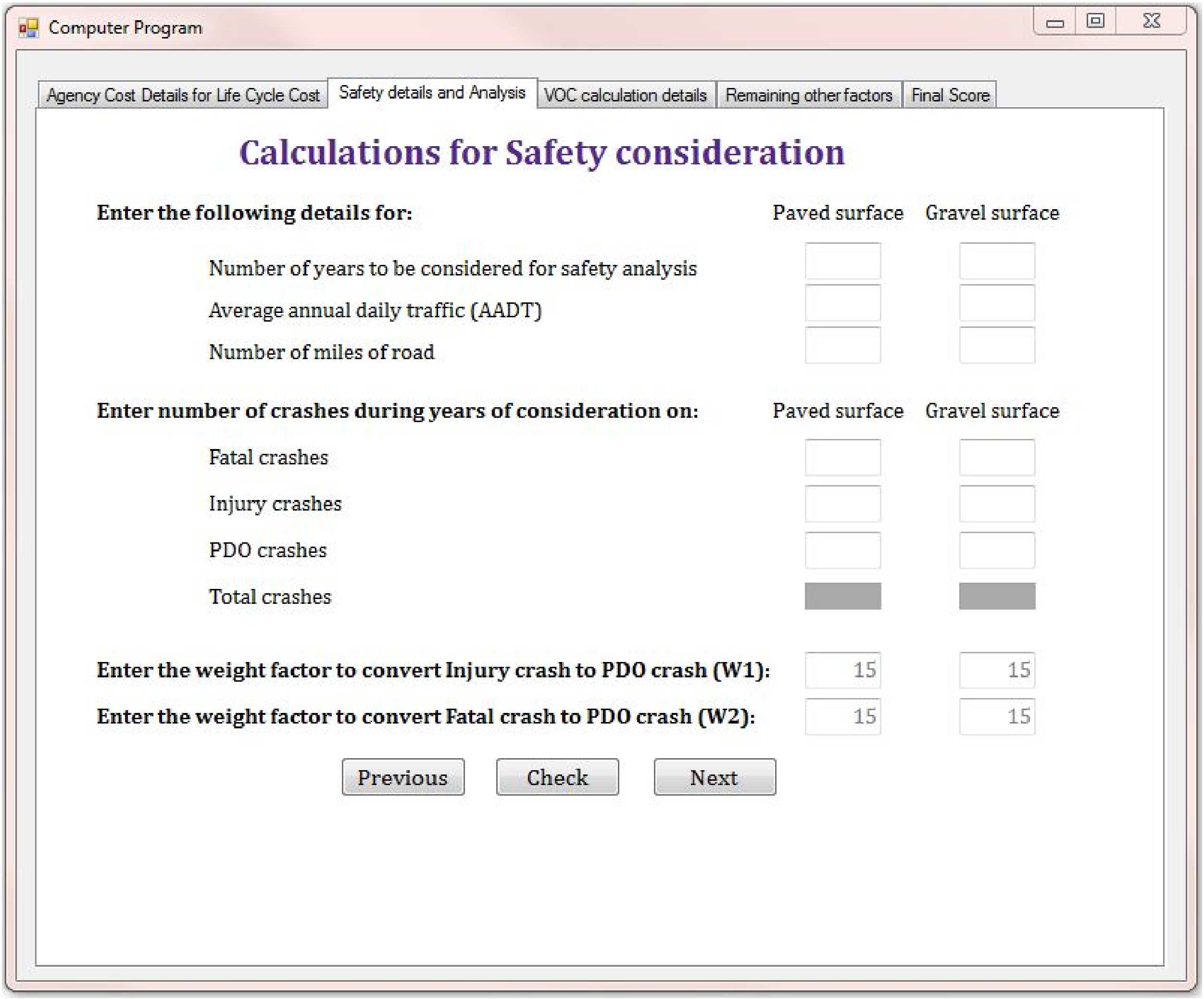

Figure F.2: User Input Layout for Calculations for Safety Consideration

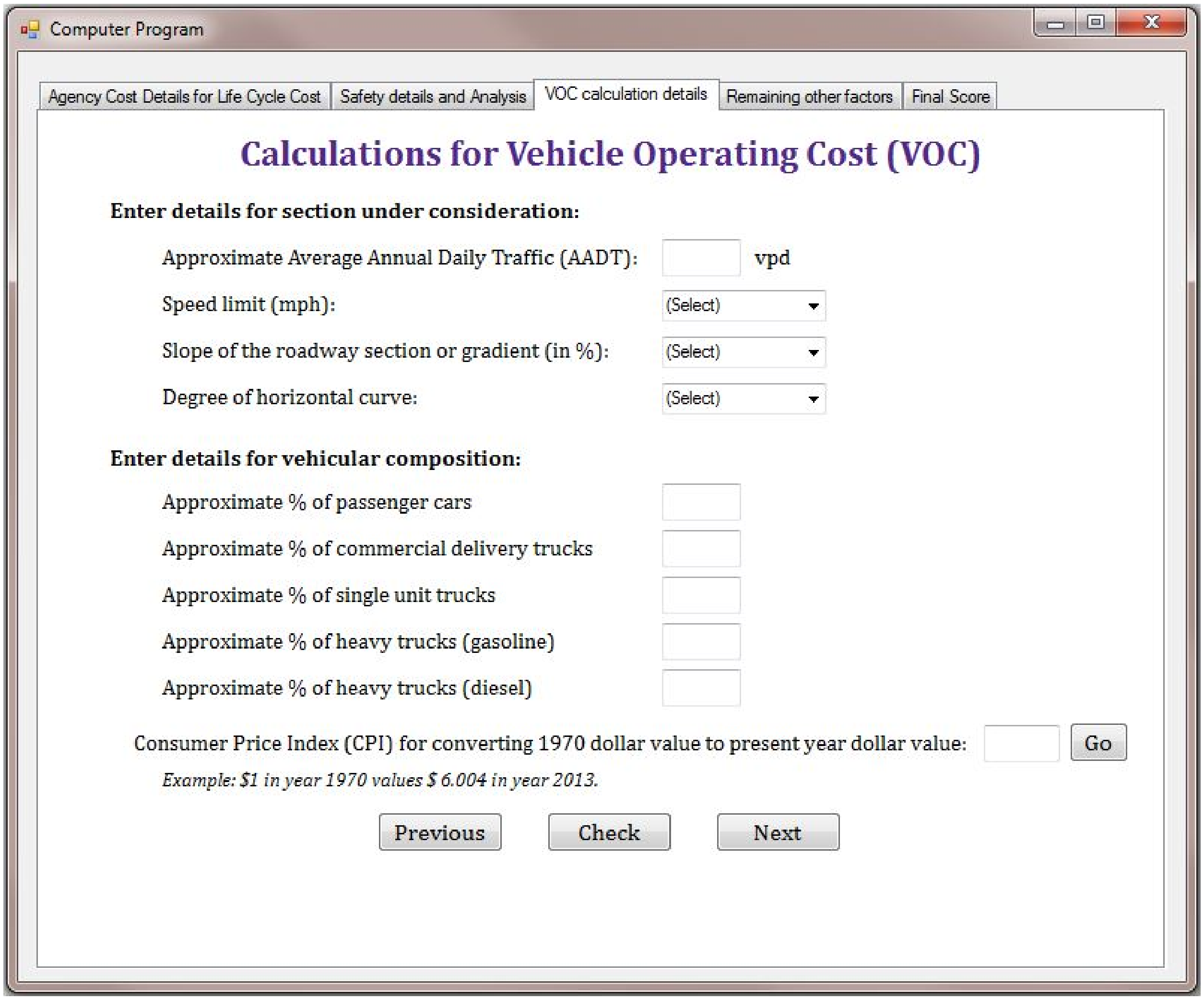

Figure F.3: User Input Layout for Calculating Vehicle Operating Cost

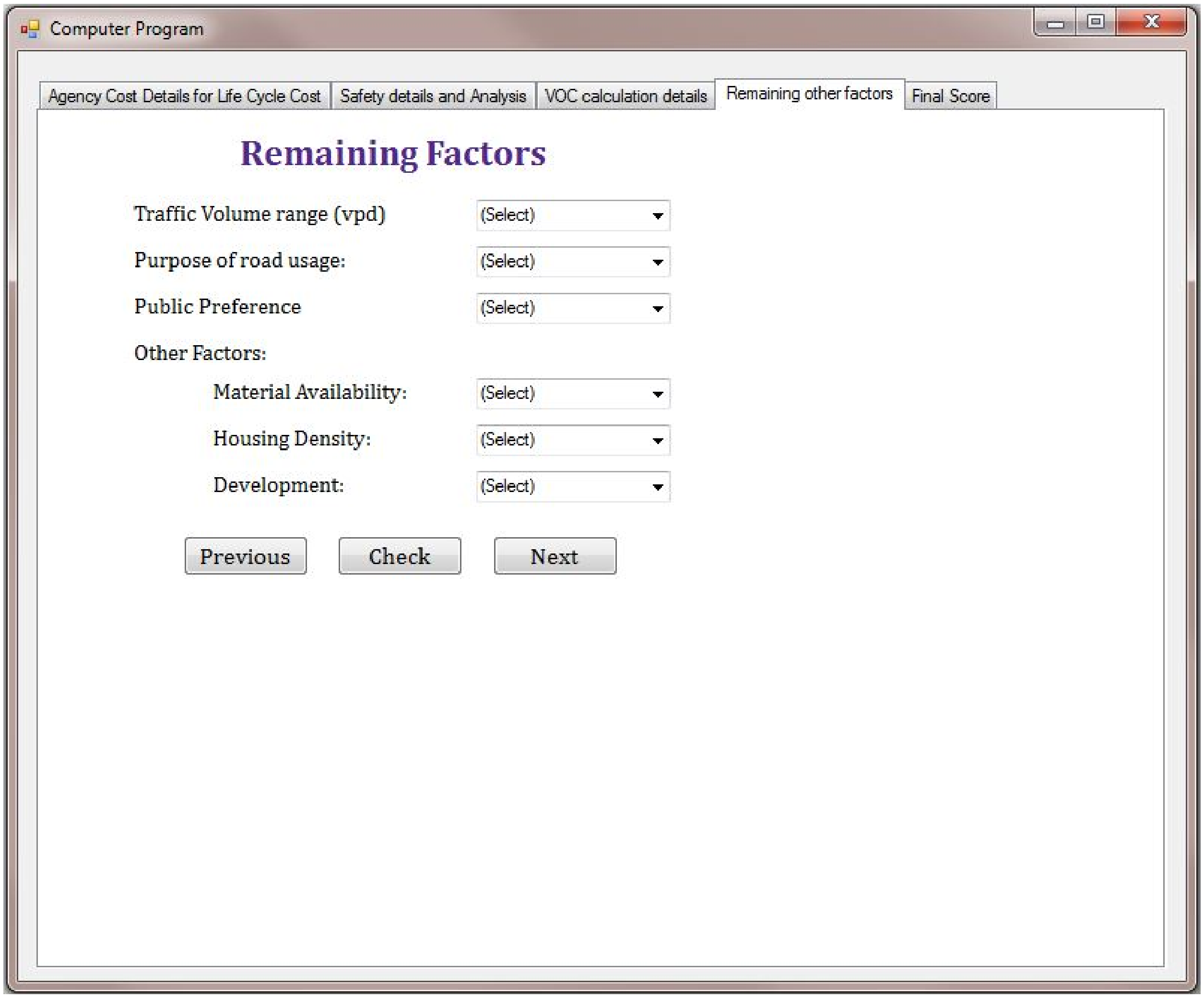

Figure F.4: User Input Layout for Remaining Factors

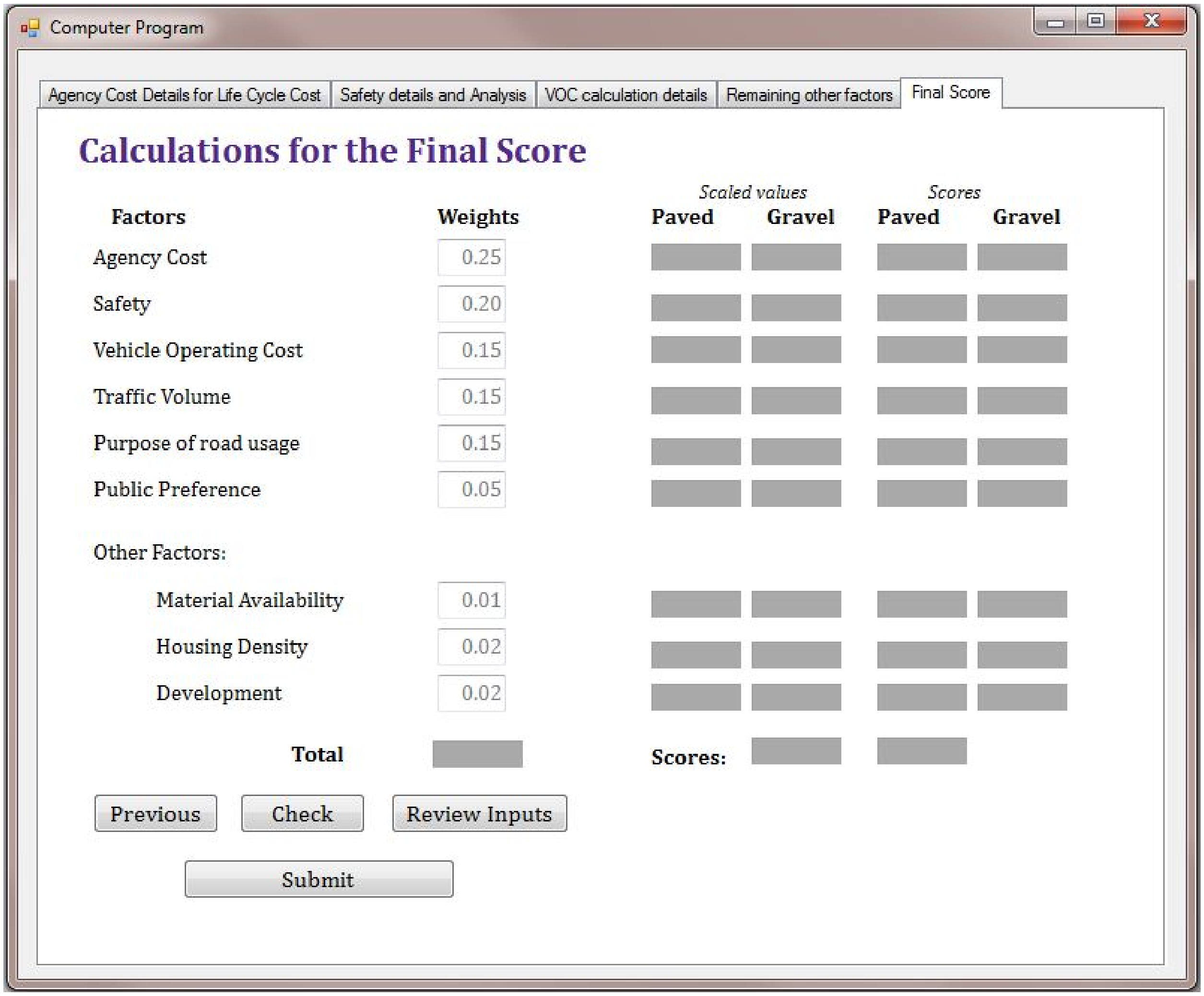

Figure F.5: Layout Showing Final Scaled Values and Scores

K-TRAN

KANSAS TRANSPORTATION RESEARCH AND NEW-DEVELOPMENT PROGRAM

Kansas
Department of Transportation