ANALYZING HIGHWAY DAMAGE COSTS ATTRIBUTED TO TRUCK TRAFFIC OF PROCESSED MEAT AND RELATED INDUSTRIES IN SOUTHWEST KANSAS

BY

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ABSTRACT

Kansas is one of the leaders in meat production in the United States. In the southwest Kansas region, there are more than three hundred feed yards and several of the biggest meat processing plants in the nation. Heavy trucks (e.g., tractor-trailers) have been used primarily for transporting processed meat, meat byproducts, grain, and other related products. With the continuous growth of the industries, there will be more trucks on highways transporting meat and meat-related products in southwest Kansas. These trucks cause noteworthy damages to Kansas highway pavements, which in turn leads to more frequent maintenance actions and ultimately more traffic delays and congestions.

The primary objective of this research was to estimate the highway damage costs attributed to the truck traffic associated with the processed meat (beef) and related industries in southwest Kansas. The researcher developed a systematic pavement damage estimation procedure that synthesized several existing methodologies including Highway Economic Requirements System (HERS) and American Association of State Highway and Transportation Officials (AASHTO) methods. In this research project, the highway section of US 50/400 between Dodge City to Garden City in Kansas was selected and its pavement data was collected for analysis. Outcomes of this research will be beneficial for the selection of cost-effective transportation modes for the meat processing and related industries in

southwest Kansas. It will also help highway agents to assess highway maintenance needs and to set up maintenance priorities. Meanwhile, the analysis results will be valuable for the determination of reasonable user costs. Based on findings of this research, recommendations on the selection of transportation modes are provided and promising future research tasks are suggested at the end of the thesis as well.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

Kansas is one of the leaders in meat production in the United States. It ranks second in the nation in cattle and calves on farms, and third in red meat production. In the southwest Kansas region, there are more than three hundred feed yards and several of the biggest meat processing plants in the nation. Figure 1.1 maps the feed yards in Kansas, and Figure 1.2 shows the major feed yards in southwest Kansas.

Traditionally, processed meat, some of the meat byproducts, grain, and other related products are transported primarily using heavy trucks (e.g., tractor-trailers). It has been estimated that the processed meat and related industries in the southwest Kansas region will continue to grow. In response to the growth of this industry, there will be more trucks on highways transporting meat or meat-related products in Kansas if other modes, including railroads, are not increasingly utilized.

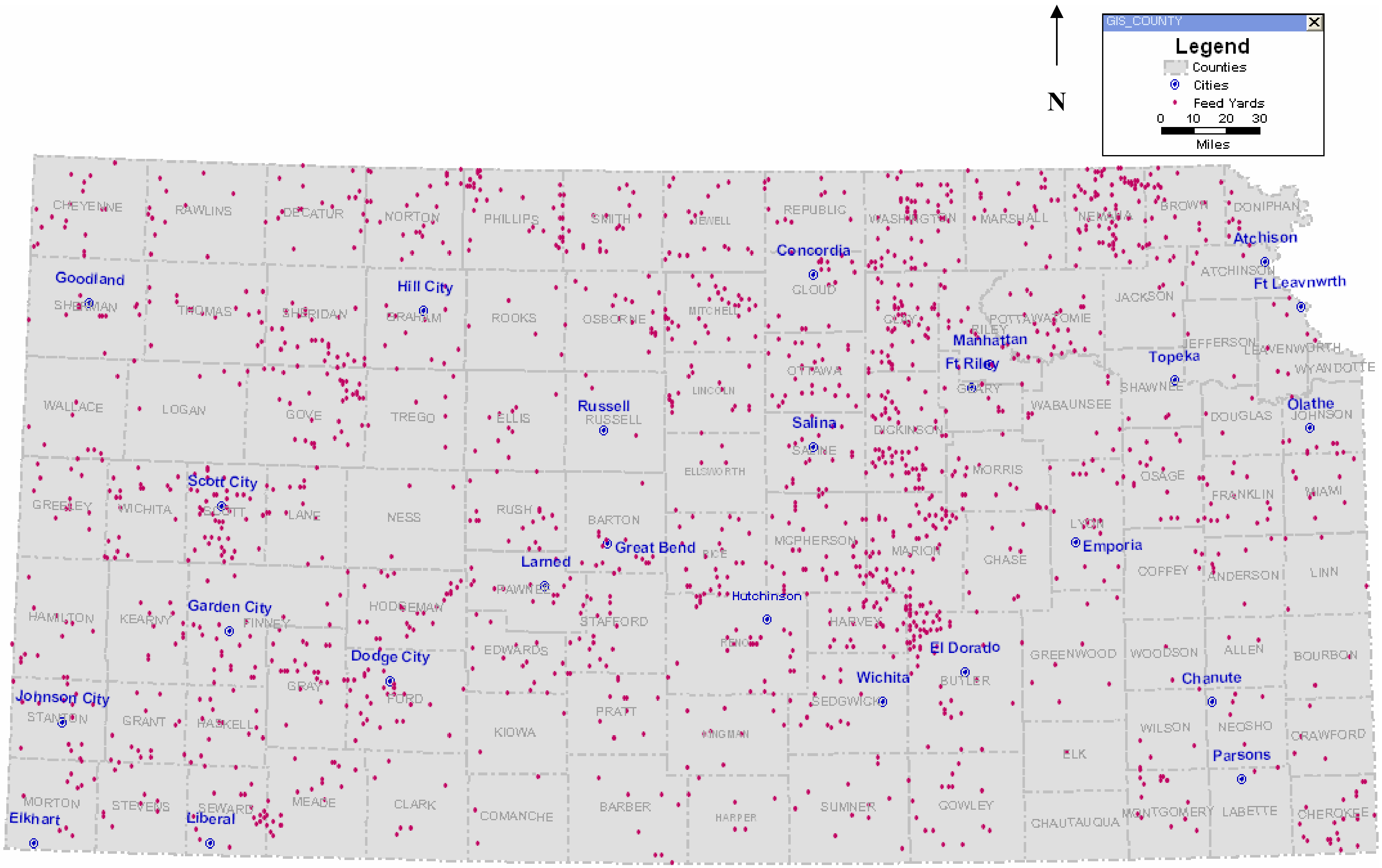


Figure 1.1 Feed Yards in Kansas (KDHE, 2005)

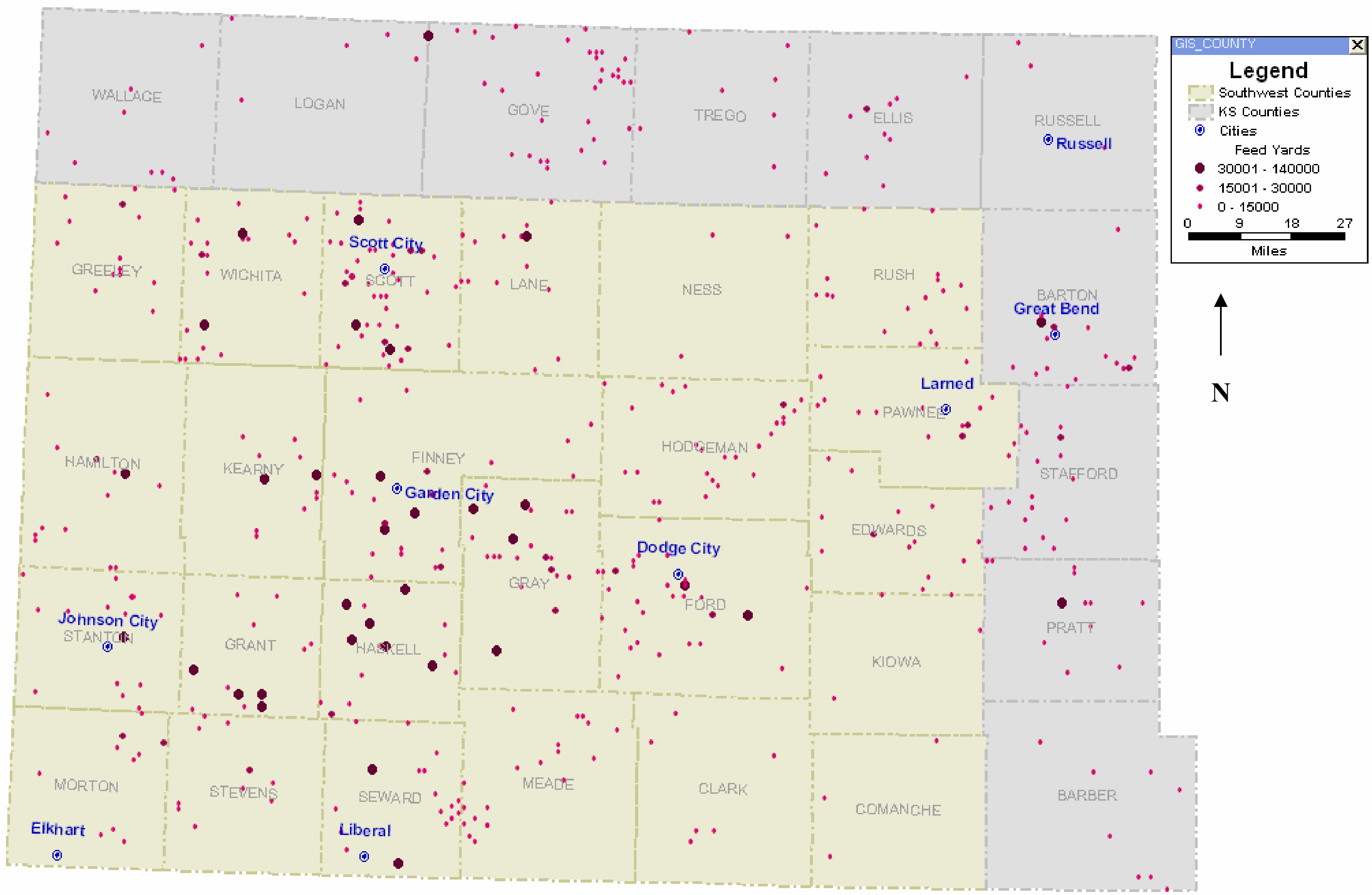


Figure 1.2 Feed Yards in Southwest Kansas (KDHE, 2006)

With the increase in truck traffic, highways will be overburdened. Increased traffic will increase traffic congestion, highway maintenance costs, frequency of roadway replacement, air pollution, fuel consumption, and travel times for road users. To address this concern, in 2006, a research project was conducted to study the utilization status of available transportation modes including truck, railroad, and intermodal in the processed meat and related industries in southwest Kansas region and their impacts on local and regional economies (Bai et al. 2007). This study concentrated on the processed beef and related industries, and included the counties of Clark, Comanche, Edwards, Finney, Ford, Grant, Gray, Greeley, Hamilton, Haskell, Hodgeman, Kearny, Kiowa, Lane, Meade, Morton, Ness, Pawnee, Rush, Scott, Seward, Stanton, Stevens, and Wichita.

To achieve the research goal, Bai et al. reviewed the current state-of-practice for the transportation of processed meat, meat by-products, feed grain, and industry-related products, followed by the pros and cons of different transportation modes used to support the meat and related industries. Second, the TransCAD software program was used to facilitate GIS-based analyses including mapping of the feed yards and processed meat plants in Kansas and in southwest Kansas region. Third, researchers collected related transportation data from various sources including state and federal government agencies, trucking and railroad companies, processed meat plants, feed yard owners, trade organizations, local economic development offices, and Web sites. To gather first hand information, two site visits to southwest Kansas, two local visits to trade organizations, and telephone interviews were conducted by the research team.

Finally, based on the collected data, vehicle miles of travel (VMT) generated by the processed meat and related industries in southwest Kansas were estimated. The total VMTs were divided into six categories listed as follows (Bai et al. 2007):

- Transporting feeder cattle to feed yards in southwest Kansas;
- Transporting feed grain to feed yards in southwest Kansas;
- Transporting finished cattle to meat processing plants in southwest Kansas;
- Transporting boxed beef to customers in the United States;
- Transporting meat byproducts to oversea customers; and
- Transporting boxed beef to oversea customers (currently market closed)

Table 1.1 presents the final results of the total daily and annual truck VMT of roundtrip shipments generated due to business activities associated with the processed meat and related industries in southwest Kansas. The research team concluded that there was a need to diversify the utilization of different modes available under the current freight transportation structure and recommended promising improvements to relieve the traffic burden caused by the processed meat and related industries in Kansas (Bai et al. 2007).

A high truck VMT can cause noteworthy damages to highways and bridges, resulting in more frequent maintenance work. There is high truck traffic on highways 50/400 and 54 in southwest Kansas that could cause rapid deterioration of these highways and higher accident rates. Also, if the planned new meat plant in Hooker, OK is built, it will increase the truck traffic on these roads. In addition, there are new business developments in the study area including: dairy farms, milk processing plants, and ethanol plants that will require more trucks on the roads unless an alternative is provided. Another factor is that many of the trucks that carry grain and cattle are over the regulated weight capacities and could cause major damage to highways. Therefore, there is an urgent need to study damage and cost issues of highways and bridges due to truck traffic.

Table 1.1 Total Daily & Annual Truck VMTs for Processed Meat and Related Industries in Southwest Kansas (Bai et al. 2007)

No.	Sequence Components	Annual VMTs	Annual VMT Percentage	Daily VMTs	Daily VMT Percentage
1	Feed Cattle to Feed Yards	9,528,888	15.40%	26,106	15.40%
2	Feed Grain to Feed Yards	9,332,302	15.10%	25,564	15.10%
3	Finished Cattle to Meat Processing Plants	23,895,800	38.70%	65,466	38.70%
4	Boxed Beef to U.S. Customers	14,096,170	22.80%	38,620	22.80%
5	Byproducts to Overseas Destinations	4,868,736	8.00%	13,338	8.00%
*6	Meat to Oversea Customers	0	0%	0	0%
Total		61,721,896	100%	169,094	100%
*Currently the overseas market is closed.					

1.2 RESEARCH OBJECTIVE AND SCOPE

The primary objective of this research was to estimate the highway damage costs attributed to the truck (e.g., tractor-trailers) traffic associated with the processed meat (beef) and related industries in southwest Kansas. This region includes the counties of Clark, Comanche, Edwards, Finney, Ford, Grant, Gray, Greeley, Hamilton, Haskell, Hodgeman, Kearny, Kiowa, Lane, Meade, Morton, Ness, Pawnee, Rush, Scott, Seward, Stanton, Stevens, and Wichita. Results of the study will be used to select cost-effective transportation modes for the meat processing and related industries in southwest Kansas region, to better assess highway maintenance needs, and to set up maintenance priorities. The analysis results could be utilized to determine reasonable user costs.

It has been estimated that several highway sections, including US 50/400 from Dodge City to Garden City, carried a significant proportion of the truck traffic generated by the processed beef and related industries in southeast Kansas (Bai et al. 2007). A significant percentage of the consequent maintenance costs for these highway sections were attributed to the heavy truck traffic. In this research project, the highway section of US 50/400 between Dodge City to Garden City was selected and its pavement data was collected for analysis.

1.3 RESEARCH METHODOLOGY

The research objective was achieved using a four-step approach including literature review, data collection, data analyses, and conclusions and recommendations.

Literature review. A comprehensive literature review was conducted first to gather the state-of-practice for the transportation of processed meat, meat by-products, feed grain, and industry-related products and to understand the highway damages associated with heavy large vehicles. The review also included the literature on Pavement Management Systems (PMS), which was a key element in the pavement data collection step. The review synthesized knowledge from sources such as journals, conference proceedings, periodicals, theses, dissertations, special reports, and government documents.

Data collection. To estimate highway damage costs associated with the processed beef and related industries, several types of data were required. Thus, truckload data on the study highway section, truck characteristics, pavement characteristics, and pavement maintenance cost data were collected from various sources.

Data analyses. In this study, the researcher used a systematic pavement damage estimation procedure that synthesized several existing methodologies including functions developed by Highway Economic Requirements System (HERS) and American Association of State Highway and Transportation Officials (AASHTO). The researcher analyzed the colleted data and utilized them in the estimation procedure to determine annual highway damage costs attributed to processed beef related industries in southwest Kansas.

Conclusions and recommendations. Based on the results of the data analyses, the researcher drew conclusions and recommendations accordingly. The conclusions included important analysis findings, possible analysis variations, and research contributions. In addition, recommendations on utilization of transportation modes, transportation infrastructure, and promising future research were provided.

1.4 THESIS ORGANIZATION

This thesis is organized into the following chapters:

Chapter 1: Introduction. This chapter presents research background information, research objective and scope, research methodology, and the organization of the thesis.

Chapter 2: Literature Review. This chapter provides information on the state-of-practices of the processed meat and related industries in southwest Kansas, fundamentals of highway damage studies attributed to heavy vehicles, and a brief introduction to the pavement management system concept.

Chapter 3: Data Collection. This chapter summarizes the data collection procedure and describes the collected data for the processed beef and related industry in southwest Kansas, including truckload data, truck characteristics, pavement characteristic data, and maintenance cost data.

Chapter 4: Estimating the annual truck VMTs associated with processed beef and related industries in southwest Kansas for the studied highway section. This is an important step before implementing the pavement damage costs analysis.

Chapter 5: Estimating highway damage costs attributed to truck traffic for processed beef and related industries. This chapter describes the data analysis procedure including analysis methodology and the data analysis outcomes.

Chapter 6: Conclusions and Recommendations. This chapter summarizes the findings of this research and provides recommendations for potential improvements and future research.

Chapter 2

LITERATURE REVIEW

A comprehensive literature review was conducted to build the research background. The knowledge from this review was synthesized and will be presented in this chapter. First, the author will present a brief introduction to the processed meat and related industries in southwest Kansas including the individual stages of the meat processing industry and the product transportation process. Then, the fundamental knowledge of highway maintenance will be provided to highlight the highway damage caused by heavy-vehicle traffic and the previous studies on heavy-vehicle-related highway cost estimation. Finally, the author will describe the pavement management system including its key components such as pavement data collection, pavement deterioration prediction, and maintenance cost analysis. The literature review included journals, conference proceedings, periodicals, theses, dissertations, special reports, and government documents.

2.1 PROCESSED MEAT INDUSTRIES IN SOUTHWEST KANSAS

Kansas ranked first in number of cattle slaughtered nationwide, second in total number of cattle, and third in the number of cattle on feed and in red meat production by commercial slaughter plants in 2004 (USDA 2005). According to the National Agricultural Statistics Service (NASS), there were 6.65 million head of cattle in Kansas, of which 2.55 million were on feed for slaughter, as of January 1, 2006 (USDA 2006a). According to Bai et al. (2007), the sequence of the transportation process involved in the processed meat industry in southwest Kansas includes several steps as shown in Figure 2.1.

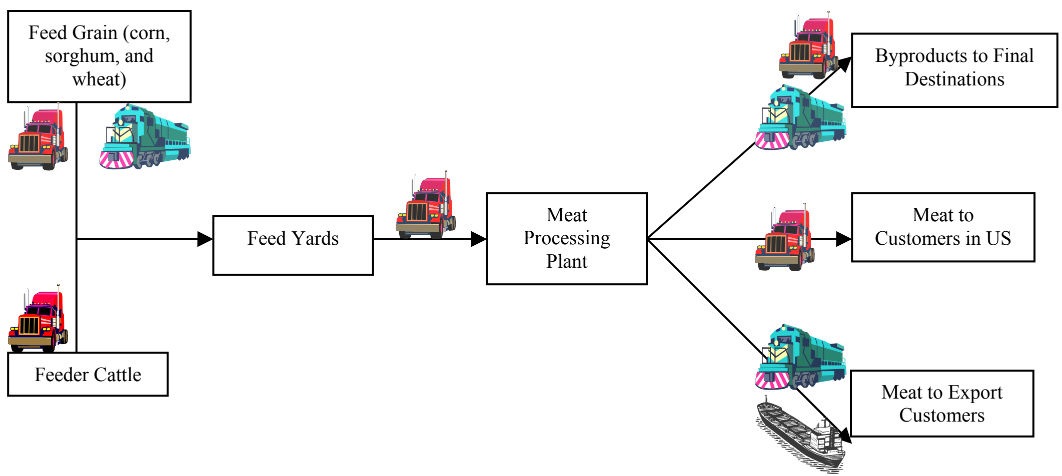


Figure 2.1 Sequence of the Kansas Meat Industry (Bai et al. 2007)

The two main inputs of feed yards are feed grains (primarily corn and sorghum, and occasionally wheat) and feeder cattle. The transport mode for feed grain is truck and/or railroad. Feeder cattle must be moved only by truck due to regulations governing the transport of live animals. Cattle are fattened at finishing feed yards in southwest Kansas and other neighboring states. Once they reach a certain weight they are then moved to meat processing plants by trucks. Thereafter, boxed beef and beef byproducts from the meat processing plants are transported via trucks or rail-truck intermodal to customers in the United States and other countries.

2.1.1 Various Stages in the Movement of Cattle

After calves are weaned, they are put up for auction and are sold to feed yards. Occasionally, some calves may be kept on a cow-calf operation longer to do background feeding (Pollan 2002). Backgrounding is a beef production system that uses pasture and other forages from the time calves are weaned until they are placed in a feed yard (Comerford et al. 2001). It is generally done for calves that are below weight to increase their weight before they are marketed (Comerford et al. 2001). Once the cattle have reached an ideal weight of around 700 pounds they will be sold to a finishing feed yard (USDA 2006c). The feeder cattle move by truck to Kansas to finish feeding, and come mainly from central Texas, New Mexico, Oklahoma, Missouri, Kentucky, Tennessee, California, and Oregon. The largest numbers come from Texas, Missouri, and Oklahoma, with lower numbers being brought from areas farther away (Petz and Heiman 2005).

2.1.2 Cattle Feeding Industry

The Kansas cattle feeding industry is a major supplier of the U.S. meat packing industry and a major component of the Kansas economy. Kansas ranks third nationwide in the number of cattle on feed, accounting for 17.9% of all cattle on feed in the U.S (USDA 2005). Kansas is an ideal location to feed cattle because the region produces large quantities of grain and silage. Also, Kansas has ideal weather to enhance cattle performance and is home to four of the largest meat packing facilities in the nation.

Cattle are finished at feed yards in southwest Kansas, where they are fed with specific rations of grain, roughage and supplements. The industry standard is around 150 days on feed (Petz and Heiman 2005). Based on the industry average, finishing cattle consume about 28 pounds of feed per head per day (Dhuyvetter 2006) and drink from 5.5 to 9.5 gallons of water per day in winter and from 14.5 to 23 gallons of water per day in summer, depending on the weather (Griffin 2002). Each feed yard has its own formula to create high quality Kansas beef, which could include grains such as corn and sorghum, protein/nutrient supplements (soybean meal, vitamins, salt, minerals, et al.), and roughage (alfalfa hay, prairie hay, corn silage and sorghum silage). In general, 75% of feed is grain (corn and sorghum) and 5-10% is a protein source.

The percentage of cattle on feed in large Kansas feed yards (1,000 head capacity or more) rose from 26.7 % in 1960 to 97.5 % in 2006, while around the same time the total number of cattle on feed increased from about 450,000 to approximately 2.55 million in 2006 (Wood, 1980; USDA 2006b). Figure 2.2 shows the increase in the number of cattle on feed from 1965-2006. According to Victor Eusebio and Stephen Rindom, Research Analysts at KDOT, the number of cattle in

Kansas feed yards is predicted to increase considerably from 1,723,000 head in 1995 to 2,654,000 head by 2020, an annual average increase of 2.2%. The top five counties with the most number of cattle on feed are Finney, Scott, Ford, Wichita and Grant. However, these production predictions are highly dependent on variable conditions, such as weather and changes to government programs (Eusebio and Rindom 1990).

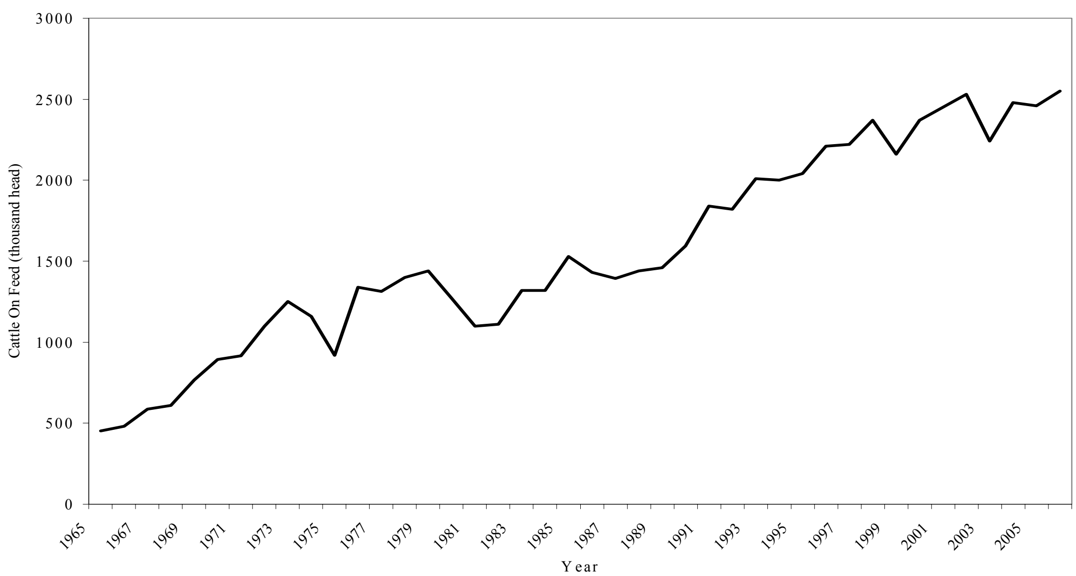


Figure 2.2 Kansas Cattle on Feed from 1965 to 2006 (USDA, 2006c)

Kansas crops produced for feed include corn, sorghum, alfalfa hay, and occasionally wheat. According to Cory Kinsley, Risk Management Director of Cattle Empire LLC in Satanta, KS, 50%-70% of grain used for feeding cattle in the region comes from outside of southwest Kansas. Grain is taken from the field to local grain elevators by trucks. An average Kansas elevator has a capacity of about 1.5 million bushels. Grain elevators purchase the grain from farmers and then sell it to feed yards.

Feed yards will have the local grain picked up and brought to the feed yards by trucks that generally only travel about 50 miles or less. Grain is also shipped to Kansas grain elevators via rail shuttle trains from various locations in Iowa, Nebraska, and Minnesota. At that point, the feed grains are trucked to the feed yards. According to Charlie Sauerwein, Grain Merchant, and Kammi Schwarting, Financial Manager of WindRiver Grain LLC in Garden City, KS, corn is shipped in from Iowa, Minnesota, and Nebraska, and is then moved within Kansas. Corn is also moved by trucks within a 30 mile radius to its destinations using independent freight companies that work on a contractual basis. Another type of feed that is used to feed cattle is soybean meal, which is shipped in from Emporia, KS, and Nebraska. Local grain that is not used in the area, mostly wheat, is shipped to other areas from local grain elevators by shuttle train.

2.1.3 Meat Processing Industry

Meat processing companies purchase fattened cattle from various feed yards. Each week, processing companies visit feed yards to survey cattle and make bids. The cattle are sold on a live weight contract base and the processing companies arrange the transportation since the packing manager needs to be in control of the efficiencies of the plant. Once live cattle are slaughtered, their meat is processed and packaged for shipment.

There are five major processing plants in Kansas with a combined daily kill capacity of 27,600 (Bai et al. 2007). Four of the five major meat (beef) processing plants are located in the southwest Kansas region and they have a combined daily kill capacity of 23,600. These plants are National Beef in Dodge City and Liberal, KS; Excel Corporation in Dodge City, KS; and Tyson Fresh Meats in Holcomb, KS. Even though these plants have a combined daily kill capacity of 23,600, it is observed that these plants do not run at full capacity the entire year because of market conditions. These plants ship boxes of refrigerated beef all over the United States year round.

2.2 FUNDAMENTALS OF HIGHWAY MAINTENANCE

"Highway maintenance" is defined as the function of preserving, repairing, and restoring a highway and keeping it in condition for safe, convenient, and economical use. "Maintenance" includes both physical maintenance activities and traffic service activities. The former includes activities such as patching, filling joints, and mowing. The latter includes painting pavement markings, erecting snow fences, removing snow, ice, and litter. Highway maintenance programs are designed to offset the effects of weather, vandalism, vegetation growth, and traffic wear and damage, as well as deterioration due to the effects of aging, material failures, and construction faults (Wright and Dixon 2004).

2.2.1 Heavy-vehicle Impact on Pavement Damage

Commonly identified pavement distress associated with heavy vehicles can be characterized as fatigue cracking and rutting. On rigid pavements, damage includes transverse cracking, corner breaking, and cracking on the wheel paths. Flexible pavements and granular roads are mostly susceptible to rutting. In all cases, cracking and rutting increase pavement roughness and reduce pavement life.

Trucking has become the most popular mode of freight transportation because of its efficiency and convenience, which has resulted in increased highway maintenance costs nationwide. To date, a large amount of research effort has been devoted to the study of the pavement damage associated with heavy vehicles. Eight studies are summarized in this section as shown in Table 2.1.

In 2001, the Wisconsin Department of Transportation District Seven released a Report of Early Distress for a 6.5-mile stretch of US 8 and an 8-mile stretch of US 51 near Rhinelander, WI (Owusu-Ababio et al. 2005). An investigation of the causes for premature failures concluded that overloaded logging trucks were a key factor leading to the early failure of doweled jointed plain concrete pavements (JPCP). Based on the recommendations from this report, Owusu-Ababio et al. (2005) developed design guidelines for heavy truck loading on concrete pavements in Wisconsin.

Table 2.1 List of Research Projects on Pavement Damage

No.	Researcher(s)	Study Subject	Data Scope	Funding Agency
1	Owusu-Ababio et al.	Effects of heavy loading on concrete pavement	Wisconsin	Wisconsin Department of Transportation
2	Phares et al.	Impacts of heavy agriculture vehicles on pavements and bridges	Minnesota	Minnesota Department of Transportation
3	Mrad et al.	Literature review on issue of vehicle/road interaction	N/A	Federal Highway Administration
4	Sebaaly et al.	Impact of agricultural equipment on low-volume roads	South Dakota	South Dakota Department of Transportation
5	Salgado et al.	Effects of super-single tires on subgrades	Indiana	Indiana Department of Transportation
6	Elseifi et al.	Pavement responses to a new generation of single wide-base tires	Virginia	Virginia Department of Transportation
7	Freeman et al.	Pavement maintenance associated with different weight limits	Virginia	Virginia Department of Transportation
8	Roberts et al.	Economic impact of overweight permitted vehicles	Louisiana	Louisiana Department of Transportation and Development

Over the past few decades, as the number of larger farms has increased and farming techniques continuously improved, it is common throughout the nation to have single-axle loads on secondary roads and bridges during harvest seasons that exceed normal load limits (typical examples are grain carts and manure wagons). Even though these load levels occur only during a short period of time during year, they may still significantly damage pavements and bridges. Phares et al. (2004) conducted a research synthesis to identify the impacts of heavy agriculture vehicles on Minnesota highway pavements and bridges. The researchers synthesized the technical literature on heavy-vehicle pavement impact provided by the Minnesota Department of Transportation (Mn/DOT) Research Services Section, which included pavement deterioration information and quantitative data from Minnesota and other Midwestern states. Based on the literature synthesis, the researchers found that performance characteristics of both rigid and flexible pavements were adversely affected by overweight implements, and the wide wheel spacing and slow moving characteristics of heavy agricultural vehicles further exacerbated the damage on roadway systems. The researchers also found that two structural performance measures, bending and punching, were used in the literature for evaluating the impact of agricultural vehicles on bridges. A comparison between the quantified structural metrics of a variety of agricultural vehicles and those of the bridge design vehicle showed that 1) the majority of the agricultural vehicles investigated created more extreme structural performance conditions on bridges when considering bending behavior, and 2) several of the agricultural vehicles exceeded design vehicle structural performance conditions based on punching.

Many studies have been done to reveal the interaction between trucks and pavement damage. Mrad et al. (1998) conducted a literature review on these studies as a part of the Federal Highway Administration (FHWA) Truck Pavement Interaction research program on truck size and weight. This review focused on spatial repeatability of dynamic wheel loads produced by heavy vehicles and its effect on pavement damage. The review included several studies identifying the effects of the environment, vehicle design, vehicle characteristics and operating conditions on pavement damage. According to the review, suspension type and characteristics, as well as tire type and configuration, were major contributors to pavement deterioration. The literature review also remarked on the relationship among spatial repeatability of dynamic wheel forces, suspension type, and road damage.

Different types of vehicles cause different types of damage to pavements. Vehicle loading on a highway pavement is highly related to axle weight and configuration. Sebaaly et al. (2002) evaluated the impact of agricultural equipment on the response of low-volume roads in the field. In this evaluation process, a gravel pavement section and a blotter pavement section in South Dakota were tested under agricultural equipment. Each section had pressure cells in the base and subgrade and deflection gauges to measure surface displacement. Field tests were carried out in different conditions in 2001. Test vehicles included two terragators (specialized tractor used to fertilize crops), a grain cart, and a tracked tractor. The field testing program collected the pavement responses under five replicates of each combination of test vehicle and load level, and compared with those responses under the 18,000-lb single-axle truck, which represented the 18,000-lb equivalent single axle load (ESAL) in the AASHTO design guide. Data were examined for repeatability, and then the average of the most repeatable set of measurements were calculated and analyzed. Results indicated that agricultural equipment could be significantly more damaging to low-volume roads than an 18,000-lb single-axle truck, and the impacts depended on factors such as season, load level, thickness of crushed aggregate base of roads, and soil type. The researchers recommended that a highway agency could effectively reduce this impact by increasing the thickness of the base layer and keeping the load as close to the legal limit as possible.

Recently, super-single tires have gradually been replacing conventional dual tires due to their efficiency and economic features. However, earlier studies on previous generations of single wide-base tires have found that the use of super-single tires would result in a significant increase in pavement damage compared to dual tires. Salgado et al. (2002) investigated the effects of super-single tires on subgrades for typical road cross-sections using plane-strain (2D) and 3D static and dynamic finite-element (FE) analyses. The analyses focused on sand and clay subgrades rather than on asphalt and base layers. The subgrades were modeled as saturated in order to investigate the effects of pore water pressures under the most severe conditions. By comparing the difference of strains in the subgrade induced by super-single tires with those induced by dual tires for the same load, the effects of overlay and subgrade improvements were shown. Several FE analyses were done by applying super-heavy loads to the typical Indiana pavements using elastic-plastic analyses in order to assess the performance of the typical pavements under the super heavy loads. The analyses showed that super-single tires caused more damage to the subgrade and that the current flexible pavement design methods were inferior considering the increased loads by super-single tires. In addition, the researchers proposed several recommendations to improve the pavement design method that would decrease the adverse effects of super-single tires on the subgrades.

Elseifi et al. (2005) measured pavement responses to a new generation of single wide-base tire compared with dual tires. The new generation of single wide-base tires has a wider tread and a greater load-carrying capacity than conventional wide-base tires, which therefore have been strongly supported by the trucking industry. The primary objective of their study was to quantify pavement damage caused by conventional dual tires and two new generations of wide-base tires (445/50R22.5 and 455/55R22.5) by using FE analysis. Fatigue cracking, primary rutting, secondary rutting, and top-down cracking were four main failure mechanisms considered in the pavement performance analysis. In the FE models developed for this research, geometry and dimensions were selected to simulate the axle configurations typically used in North America. The models also considered actual tire tread sizes and applicable contact pressure for each tread, and incorporated laboratory-measured pavement material properties. The researchers calibrated and validated the models based on stress and strain measurements obtained from the experimental program. Pavement damage was calculated at a reference temperature of 77 °F and at two vehicle speeds (5 and 65 mph). Results indicated that the new generations of wide-base tire would cause the same or greater pavement damage than conventional dual tires.

Because heavy trucks cause more damage to highways, it is of interest to federal and state legislatures whether the current permitted weight limit reflects the best tradeoff between trucking productivity and highway maintenance cost. A study (Freeman et al. 2002) was mandated by Virginia's General Assembly to determine if pavements in the southwest region of the state under higher allowable weight limit provisions had greater maintenance and rehabilitation requirements than pavements bound by lower weight limits elsewhere. This study included traffic classification, weight surveys, an investigation of subsurface conditions, and comprehensive structural evaluations, which were conducted at 18 in-service pavement sites. Visible surface distress, ride quality, wheel path rutting, and structural capacity were measured during 1999 and 2000. A subsurface investigation was conducted at each site in October 1999 to document pavement construction history and subgrade support conditions. In addition, a survey consisting of vehicle counts, classifications, and approximate measurements of weights was carried out to collect site-specific information about traffic volume and composition. The results were used to estimate the cost of damage attributed only to the net increase in allowable weight limits. The study concluded that pavement damage increased drastically with relatively small increases in truck weight. The cost of damage to roadway pavements in those counties with a higher allowable weight limit was estimated to be $28 million over a 12-year period, which did not include costs associated with damage to bridges and motorist delays through work zones and so forth.

In Louisiana, Roberts (2005) completed a study to assess the economic impact of overweight vehicles hauling timber, lignite coal, and coke fuel on highways and bridges. First, researchers identified key 1,400 control sections on Louisiana highways that carried timber, 4 control sections that carried lignite coal, and approximately 2,800 bridges that were involved in the transport of both of these commodities. Second, a calculation methodology was developed to estimate the overlays required to support the transportation of these commodities under the various gross vehicle weight (GVW) scenarios. Three different GVW scenarios were selected for this study including: 1) 80,000 lbs., 2) 86,600 lbs. or 88,000 lbs., and 3) 100,000 lbs. Finally, a methodology for analyzing the effect of these loads on pavements was developed and it involved determining the overlay thickness required to carry traffic from each GVW scenario for the overlay design period. In addition, a method of analyzing the bridge costs was developed using the following two steps: 1) determining the shear, moment and deflection induced on each bridge type and span, and 2) developing a cost of repairing fatigue damage for each vehicle passage with a maximum tandem load of 48,000 lbs. This analysis showed that 48 kilo pounds (kips) axles produced more pavement damage than the current permitted GVW for timber trucks and caused significant bridge damage at all GVW scenarios included in the study. The researchers recommended that the legislature eliminate the 48-kip maximum individual axle load and keep GVWs at the current level, but increase the permit fees to sufficiently cover the additional pavement costs produced by overweight vehicles.

2.2.2 Pavement Damage Cost Studies

A total of about 4,000,000 miles of roads, including 46,572 miles of Interstate highways and over 100,000 miles of other national highways, form the backbone of the United States highway infrastructure. Careful planning considerations and wise investment decisions are necessary for the maintenance of the nation's massive infrastructure to support a sufficient level of operations and provide a satisfied degree of serviceability. Studies have found that trucks place heavy loads on pavement, which lead to significant road damage, therefore resulting in increased highway maintenance costs nationwide. Several studies addressing the pavement damage costs are summarized in this section, as listed in Table 2.2.

Table 2.2 List of Research Projects on Maintenance Costs

No.	Researcher(s)	Study Subject	Study Scope	Funding Agency
1	Boile et al.	Infrastructure costs associated with heavy vehicles	New Jersey	New Jersey Department of Transportation
2	Martin	Road wear cost for thin bituminous-surfaced arterial roads	Australia	Austroads (association of state and federal road agencies)
3	Hajek et al.	Pavement cost changes in new regulations of truck weights and dimensions	Ontario, Canada	N/A
4	Babcock et al.	Road damage costs related to the abandonment of shortline railroads	Western and central Kansas	Kansas Department of Transportation
5	Lenzi et al.	Road damage costs resulting from drawdown of the lower Snake River.	Washington	Washington Department of Transportation
6	Russell et al.	Road damage costs related to the abandonment of railroad branchline	South and western Kansas	Kansas Department of Transportation
7	Tolliver et al.	Road damage cost associated with the loss of rail service	Washington	Washington Department of Transportation

Boile et al. (2001) conducted a study on infrastructure costs attributed to heavy vehicles. The first objective of the study was to review literature and determine the availability of methods for estimating highway maintenance costs due to bus and truck traffic in New Jersey, along with the availability of existing data. The second objective was to determine the existence and availability of methodologies to estimate the impact of different types of buses on the highway infrastructure. Two broad areas of related literature were reviewed in the study, including 1) highway cost allocation studies, or estimating highway related costs attributable to heavy vehicles; and 2) the developing models to estimate pavement deterioration as a result of vehicle-pavement interactions. The existing highway cost allocation methods were categorized into four groups: cost-occasioned approaches, benefit-based approaches, marginal cost approaches, and incremental approaches. A federal, as well as several state highway cost allocation studies, were reviewed in the research and all of them used cost-occasioned approaches. The approaches used in these studies varied in data requirements, ease of use and updating, and output detail. Regarding pavement deterioration estimation, several types of models had been developed for flexible and rigid pavements, including statistical models, subjective models, empirical deterioration models, mechanistic/empirical models, and mechanized models. In addition, the researchers reviewed the literature addressing bus impacts on pavements. Finally, the researchers concluded that: 1) performing a cost allocation study would be highly recommended since it could help develop a clear picture of the cost responsibility of each vehicle class and decide whether changes need to be made in order to charge each vehicle class its fair share of cost responsibility. 2) Two of the statewide cost allocation approaches might provide useful guidelines in developing a relatively easy to use and updated model. This research also presented a proposed method for estimating bus impacts on New Jersey highways, which was based on estimates of Equivalent Single Axle Loads (ESALs) with a step-by-step guide on how to apply the method.

Load-related road wear is considered to be an approximation for the marginal cost of road damage. Due to their high axle loads, heavy vehicles are considered to be primarily responsible for road wear. Martin (2002) estimated road wear cost for thin bituminous-surfaced arterial roads in Australia, which was based on the following two approaches: 1) a statistical relationship between the road maintenance costs and a heavy-vehicle-road-use variable; and 2) a pavement deterioration model that estimated the portion of load-related road wear based on pavement deterioration predictions for thin bituminous-surfaced granular pavements. The data used in the study were collected from the following sources covering all Australian states: 1) 255 arterial road samples, composed of 171 rural and 84 urban samples, varying in average length from 30 km (18.6 miles) in rural area to 0.15 km (0.09 miles) in urban area; 2) three years of maintenance expenditure data in estimating the annual average maintenance cost at each road sample; and 3) estimates of road use at each road sample. The study found that 55% to 65% of the recent estimates of road wear cost were due to heavy vehicles for the average level of traffic loading on the bituminous surfaced arterial road network of Australia. The researchers suggested that the fourth power of the law-based ESAL road-use variable could be used for estimating road wear costs.

Hajek et al. (1998) developed a marginal cost method for estimating pavement cost from proposed changes in regulations governing truck weights and dimensions in Ontario, Canada. The procedure was part of a comprehensive study undertaken by the Ontario Ministry of Transportation in response to government and industry initiatives to harmonize Ontario's truck regulations with those in surrounding jurisdictions. The study investigated the individual impacts of four proposed alternative regulatory scenarios. The differences between the scenarios were relatively small and were directed only at trucks with six or more axles. The procedure for assessing pavement costs consisted of three phases: 1) identification of new traffic streams; 2) allocation of these new traffic streams to the highway system; and 3) assessment of cost impacts of the new traffic streams on the pavement network. The marginal pavement cost of truck damage was defined as a unit cost of providing pavement structure for one additional passage of a unit truckload (expressed as ESAL). The marginal pavement costs were calculated as annualized life-cycle costs and expressed as equivalent uniform annual costs (EUACs). The study concluded that: 1) the marginal cost method could be used to quantify relatively minor changes in axle weights and pavement damage caused by any axle load, or axle load arrangement for both new and in-service pavements; and 2) the highway type (or truck volumes associated with the highway type) had a major influence on marginal cost.

Babcock et al. (2003) conducted a study to estimate road damage costs caused by increased truck traffic resulting from the proposed abandonment of shortline railroads serving western and central Kansas. The study area included the western two-thirds of the state. The four shortlines assumed to be abandoned were: the Central Kansas Railroad (CKR), the Kyle Railroad, the Cimarron Valley Railroad (CVR), and the Nebraska, Kansas and Colorado Railnet (NKC). Their objective was achieved in a three-step approach. First, a transportation cost model was developed to compute how many wheat car loadings occurred at each station on each of the four-shortline railroads in the study area. Then, the shortline railroad car loadings at each station were converted to truckloads at a ratio of one rail carload equal to four truck loads. Finally, a pavement damage model presented by Tolliver (2000) was employed to calculate the additional damage costs for county and state roads attributed to the increased grain trucking due to shortline abandonment. The study also used a time decay model and an ESAL model to examine how increased truck traffic affected pavement service life. Pavement data inputs required by the models used in the study included designation as U.S., Kansas, or Interstate highway, transportation route number, beginning and ending points of highway segments by street, mile marker, or other landmarks, length of pavement segment, soil support values, pavement structural numbers, annual 18-kip traffic loads, and remaining 18-kip traffic loads until substantial maintenance or reconstruction. These data were obtained from the KDOT CANSYS database. The road damage cost resulting from abandonment of the short line railroads in the study area could be divided into two parts: 1) costs associated with truck transportation of wheat from farms to county elevators; and 2) costs of truck transportation of wheat from county elevators to shuttle train stations and terminal elevators. The study found that the shortline railroad system in the study area annually saved $57.8 million in road damage costs.

In eastern Washington, grain shippers were utilizing the Lower Snake River for inexpensive grain transportation. However, the truck-barge grain transportation with longer distances resulted in higher damage costs for the principal highways in this geographical area. Lenzi et al. (1996) conducted a study to estimate the deduction of the state and county road damage costs in Washington by proposing a drawdown usage of the Lower Snake River. The researchers proposed two potential drawdown scenarios. Scenario I assumed that the duration of drawdown was from April 15 to June 15; and scenario II assumed that the duration of the drawdown was from April 15 to August 15. During the drawdown, trucking would be the only assumed shipping mode to the nearest elevators with rail service. Since the average length of haul for a truck to an elevator was estimated as 15 miles compared with 45 miles for truck-barge movements, the shifting from truck-barge mode to truck-rail mode would result in less truck miles traveled and thus would cause a significant reduction of highway damage. Based on a series of assumptions suggested by similar studies, the total road damage costs before the Lower Snake River drawdown was estimated as $1,257,080 for Scenario I. The road damage cost after Scenario I drawdown was calculated in a similar manner at $459,770, or 63% less than the pre-drawdown cost. For scenario II, the drawdown was estimated to be able to reduce road damage costs by $1,225,540, or 63% than the pre-drawdown costs which was estimated as $3,352,240. The researchers concluded that with adequate rail car supply, both drawdown scenarios would decrease the system-wide highway damage costs, although certain roadways might experience accelerated damages.

Russell et al. (1996) conducted a study to estimate potential road damage costs resulting from hypothetical abandonment of 800 miles of railroad branchline in south central and western Kansas. First, the researchers adopted a wheat logistics network model developed by Chow (1985) to measure truck and rail shipment changes in grain transportation due to railroad abandonment. The model contained 400 simulated farms in the study area. The objective function of this model was to minimize the total transport cost of moving Kansas wheat from the simulated farms to county elevators, then from county elevators to Kansas railroad terminals, and then from railroad terminals to export terminals in Houston, TX. The model was employed for both the base case (truck and railroad wheat movements assuming no abandonment of branchlines) and the study case (after the abandonment of branch lines). Second, the researchers measured the pavement life of each highway segment in ESALs using Highway Performance Monitoring System (HPMS) pavement functions. Finally, they estimated road damage in ESALs for each type of truck by using the AASHTO traffic equivalency functions. Results indicated that annual farm-to-elevator road damage costs before abandonment totaled $638,613 and these costs would increase by $273,359 after abandonment. Elevator-to-terminal road damage costs before the abandonment were $1,451,494 and would increase by $731,231 after the abandonment. Thus the total abandonment related road damage costs would add up to $1,004,590.

Tolliver et al. (1994) developed a method to measure road damage cost associated with the decline or loss of rail service in Washington State. Three potential scenarios were assumed in the study: 1) the system-wide loss of mainline rail services in Washington; 2) the loss of all branchline rail service in Washington; and 3) all growth in port traffic was diverted to trucks due to potential loss of railroad mainline capacity. The study used AASHTO procedures to estimate pavement deterioration rates and HPMS damage functions to measure the pavement life of highway segments in ESALs. The research objective was achieved by using the following steps: 1) defining the maximum feasible life of an impacted pavement in years, 2) determining the life of a pavement in terms of traffic by using a standard measurement of ESALs, 3) computing the loss of Present Serviceability Rating (PSR) from a time decay function for a typical design performance period, 4) calculating an average cost per ESAL, and 5) computing the avoidable road damage cost if the railroads were not abandoned. For Scenario 1, the researchers estimated that the incremental annual pavement resurfacing cost would be $65 million and the annual pavement reconstruction cost would be $219.6 million. For Scenario 2, the study found that the annual resurfacing costs would range from $17.4 to $28.5 million and the annual reconstruction cost would vary from $63.3 million to $104 million with different truck configurations. In Scenario 3, the incremental annual pavement resurfacing costs would be $63.3 million and the annual reconstruction cost would be $227.5 million.

2.3 PAVEMENT MANAGEMENT SYSTEM

In the past, pavements were maintained but not managed. Life-cycle costing and priority were not considered as important factors in the selection of maintenance and rehabilitation (M&R) techniques. Today's economic environment requires a more systematic approach to determining M&R needs and priorities (Shahin 1994). All pavements deteriorate over time due to traffic and environment. The growth of truck traffic is of special importance to pavement engineers and managers since one major cause of pavement deterioration is truck traffic. Figure 2.3 is a curve that has been normally used to demonstrate the relationship between repair time and cost. It shows the average rate of deterioration for an agency and the change in repair costs as the pavement deteriorates. The evidence reveals that the overall costs will be smaller if the pavement is repaired earlier rather than later. In 1989, the FHWA established a policy saying that all states must have a pavement management system (PMS) to manage their Federal Aid Primary Highway System (Interstate and Principal Highways). As a result of this policy, all states were required to develop and implement a PMS as one of many conditions for federal funding.

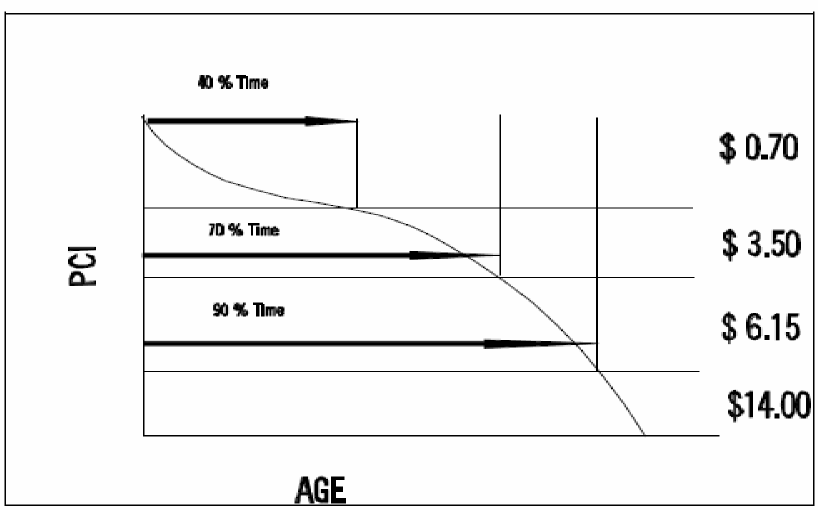


Figure 2.3 Effect of Treatment Timing on Repair Costs (AASHTO, 2001)

A pavement management system (PMS) is a set of tools or methods that assist decision-makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time (AASHTO 1993). Pavement management is generally described, developed, and used in two levels: network level and project level (AASHTO 1990). These two levels differ in both management application and data collected (FHWA 1995). The primary results of network-level analysis include M&R needs, funding needs, forecasted future impacts on various funding options considered, and prioritized listings of candidate projects that need to be repaired for the evaluated options. The purpose of project-level analysis is to provide the most cost-effective, feasible, and original design, maintenance, rehabilitation, or reconstruction strategy possible for a selected section of pavement within available funds and other constraints (AASHTO 2001). Generally speaking, a PMS contains three primary components (USDOT and FHWA 1998): 1) *data collection*: including inventory, history, condition survey, traffic, and database; 2) *analyses*: including condition, performance, investment, engineering and feedback analyses; and 3) *update*.

In the past three decades, PMS has been significantly improved. The early systems used simple data-processing methods to evaluate and rank candidate pavement rehabilitation projects only based on current pavement condition and traffic, with no consideration of future pavement condition forecasting and economic analysis. Systems developed in the 1990s use integrated techniques of performance prediction, network- and project-level optimization, multi-component prioritization, and geographic information systems (GIS) (Kulkarni and Miller 2003). A mature PMS includes three key components: data collection, deterioration prediction, and cost analysis which are described as follows.

Data Collection

Data collection is an essential element of an efficient PMS. The data collection program should focus on the following objectives: timeliness of collecting, processing, and recording data in the system; accuracy and precision of the data collected; and integration. The major data components include the following:

- Inventory: physical pavement features including the number of lanes, length, width, surface type, functional classification, and shoulder information;
- History: project dates, types of construction, reconstruction, rehabilitation, and preventive maintenance;
- Condition survey: roughness of ride, pavement distress, rutting, and surface friction;
- Traffic: volume, vehicle type, and load data; and
- Database: compilation of all data files used in the PMS.

Among these components, collecting condition survey data is the most expensive activity needed to keep the data current for a PMS. The types of pavement condition assessment data include roughness (ride quality), surface friction (skid resistance), structural capacity, and selected surface distresses including rutting, cracking, shoving, bleeding, and faulting.

Roughness is probably the most important pavement performance parameter to the highway users. It is a direct measure of the riding comfort as one travels down the roadway. Historically, the PSR was used as the standard measure of pavement roughness. Currently, the International Roughness Index (IRI) is used as the principal method to measure roughness and to relate it to riding comfort. NCHRP Report 228 (TRB 1980) described more details of the mathematical model used to calculate IRI. Measuring pavement roughness is a much easier task with the advent of new technologies. The three most commonly used types of devices for measuring roughness at the network-level are response type road roughness measurement equipment (RTRRMSs), inertial profilers, and the accelerometer based RTRRMS (Haas et al. 1994). In addition, NCHRP Synthesis 203, "Current Practices in Determining Pavement Condition" (TRB 1994) provides an overview of the different techniques used by state DOTs to measure pavement roughness; and NCHRP Report 434, "Guidelines for Longitudinal Pavement Profile Management," identifies profile measurement factors that affect the accuracy of measured parameters and provides guidelines to help improve the results of the measurements (Karamihas et al. 1999). The proposed AASHTO provisional standard specifies that, as a minimum, the following data should be collected and recorded:

- Section identification;
- IRI for each wheelpath of the outside lane (m/km);
- The average IRI for both wheel paths (m/km);
- Date of data collection; and

- Length of the pavement section (in meters).

Equipment-based measurements of the severity of different pavement distresses are common for conducting pavement condition surveys. According to a 1996 survey by FHWA, which included information from 52 agencies, the major forms of distress being measured and included in respective PMS database are rutting, faulting, and cracking. Presently, there are several widely recognized standards for identifying and collecting pavement distress data. At the national level, SHRP publication P-338, entitled “Distress Identification Manual for the Long-Term Pavement Performance Project” (NRC 1993) is the most widely recognized standard for manual pavement condition data collection at the state level.

Pavement Deterioration Prediction

Many of the analysis packages used in a PMS require pavement performance prediction models. A condition prediction model allows agencies to forecast the condition of each pavement segment from a common starting point. The pavement performance prediction element involves the prediction of future pavement conditions under specified traffic loading and environmental conditions. Reliable pavement performance prediction models are crucial for identifying the least-cost rehabilitation strategies that maintain desired levels of pavement performance.

Darter (1980) outlined basic requirements for a reliable prediction model as follows:

- An adequate database based on in-service segments;
- Consideration of all factors that affect performance;

- Selection of an appropriate functional form of the model; and
- A method to assess the precision and accuracy of the model.

There are a large number of variables that affect how pavement elements perform (AASHTO 1993), which include structural loadings, support (often natural soil), properties and arrangement of layer materials, and environment.

Early systems only evaluated pavement conditions at a specific time; they did not have a predictive element. Later, relatively simple prediction models were introduced. These models were generally based on engineering judgment of the expected design life of different rehabilitation actions. The most popular models used currently fall in several categories based on the model development methodologies (AASHTO 2001):

- *Bayesian models*. These generally combine observed data and expert experience using Bayesian statistical approaches (Smith et al. 1979; Haper and Majidzadeh 1991). The main feature of Bayesian models is that the prior models can be initially developed using past experience or expert opinion, and then the models can be adjusted using available field data or vice-versa (first data, then judgment) to get the posterior models. However, other prediction equations can also be formulated exclusively from past experience.
- *Probabilistic models.* Stochastic models are considered more representative of actual pavement performance since there is considerable variation in the condition of similar sections, even among replicated sections. Probabilistic models predict the probability that the condition will change from one

condition level to another at some given point of the pavement life defined in time, traffic, or a combination of both.

- *Empirical models.* They relate the change in condition to the age of the pavement, loadings, or some combination of both (Lytton 1987). Regression analysis is a statistical method commonly used to assist in finding the best empirical model that represents the data. However, a newer generation of methods, such as fuzzy sets, artificial neural networks, fuzzy neural networks, and genetic algorithms, can also be used for the development of performance models. These types of models are only valid for predicting the condition of segments similar to those on which the models were based and they must be carefully examined to ensure they are realistic. In addition, an agency's routine maintenance policy may significantly affect the predicted condition, and a model developed in one agency, with a defined routine maintenance policy, may not be appropriate for use by another agency using another maintenance policy (Ramaswamy and Ben-Akiva 1990).
- *Mechanistic-empirical models.* These are models in which responses such as strain, deformation, or stress are predicted by mechanistic models. The mechanistic models are then correlated with a usage or environmental variable, such as loadings or age, to predict observed performance such as distress. In mechanistic-empirical procedures, a mechanistic model is used to predict the pavement response. Empirical analysis is used to relate these responses to observed conditions to develop the prediction models. The link

between material response and pavement distress can be illustrated with a load equivalency factor and the concept of the equivalent single axle load (ESAL), which was developed from the AASHO Road Test. Most mechanistic-empirical models are used at the project level and very few are used at the network level.

- *Mechanized models.* These exclude all empirical interference on the calculated pavement deterioration and intend to calculate all responses and their pavement structure purely mechanistically. Commonly used mechanistic models in pavement analysis include layered elastic and finite element methods. However, these types of models require detailed structural information, which limits the accurate calculation of stresses, strains, and deflections to sections for which detailed data are available. While mechanistic evaluation of materials subjected to different types of loading has provided valuable insights into how pavements behave, no pure mechanistic condition prediction models are currently available.

The last three models, empirical models, mechanistic-empirical models and mechanized models, are generally considered deterministic models because they predict a single value for the condition or the time to reach a designated condition.

Cost Analysis

To determine the infrastructure cost responsibility of various vehicles classes, Highway Cost Allocation Studies (HCAS) were conducted by the US DOT and several State DOTs. A HCAS is an attempt to compare revenues collected from various highway users to expenses incurred by highway agencies in providing and maintaining facilities for these users. The latest Federal HCAS (FHCAS) was done in 1997. The base period for this study was 1993-1995 and the analysis year was 2000. Costs for pavement reconstruction, rehabilitation, and resurfacing (3R) were allocated to different vehicle classes on the basis of each vehicle's estimated contribution to pavement distresses necessitating the improvements.

In a PMS, cost analysis involves quantifying the various components of cost for alternative rehabilitation strategies so that the least-cost alternative can be identified. Early systems only used the initial construction costs of rehabilitation actions, and did not analyze user costs and calculated life-cycle costs. Present systems analyze both agency costs and user costs, which include single- and multi-year period analyses and consider life-cycle cost.

Chapter 3

DATA COLLECTION

The estimation of highway damage costs associated with southeast Kansas processed beef and related industries required several types of information. The information included truckload data on the highway section under study, truck characteristics, pavement characteristics data, and pavement maintenance cost data. Truckload data reflects the truck traffic on the highway section. Truck characteristics data are the characteristics of the trucks primarily used for the beef-related industry in southwest Kansas. Required pavement characteristics data for this study included the data describing pavement type, length, structure, distress survey, and PSR performance. This information was important for the pavement deterioration analysis. Pavement maintenance cost data also needed to be collected to estimate average unit cost of the highway section. The following sections describe the required data in detail that were used for this research.

3.1 TRUCKLOAD DATA

Modeling of traffic loadings is one important aspect not only in the pavement design procedures but in the pavement deterioration models. To conduct this pavement damage cost study, the first step was to estimate the annual truck VMTs attributed to the processed beef and related industries on the highway pavement section under study. This estimation required the annual truckload data on the studied highway section. In the previous project by Bai et al. (2007), the truckloads generated by the processed beef and related industries in the southeast Kansas area had been estimated, including highway US 50/400 between Garden City and Dodge City. The truckload data from a previous project was utilized for this research. Details of truckload data will be further described in Chapter 4.

3.2 TRUCK CHARACTERISTICS AND TYPE

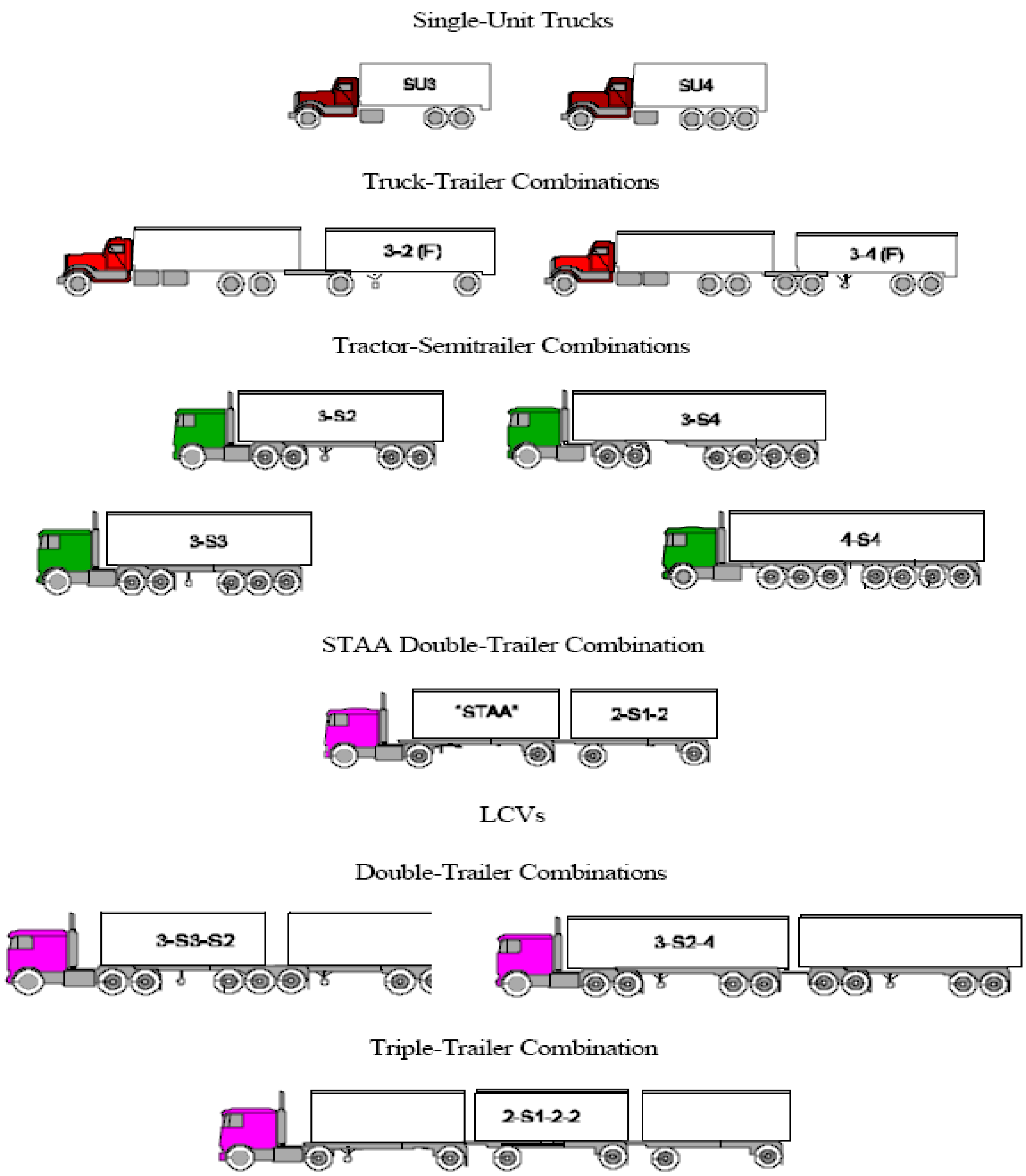
The trucking industry has become a key player in the movement of freight in the American economy because of its obvious advantages, such as promptness, supervised nature, refrigeration, and effective tracking. Trucking has been the predominant mode of freight transport for processed meat industry in southwest Kansas (Bai et al. 2007). Truck characteristics determine how the weight of trucks is actually applied to highway pavements. Vehicle weight results in pavement damage as vehicles travel along paved surfaces. Vehicle weight is frequently referred as the gross vehicle weight (GVW) or the total weight of the vehicle. GVW is the fixed weight of the vehicle, such as the equipment, fuel, body, payload, and driver on the basis of an individual unit, such as a truck or tractor (Roadway Express 2005; General Motors 2006). However, GVW is not directly related to pavement deterioration. Axles distribute the weight of a vehicle to a road surface, so pavement stress results from the loads applied by axles or axle groups. In general, more axles result in less pavement stress. Axle spacing also affects pavement loading. Axles placed close together apply a load with less pavement stress (US DOT 2000). It is possible for a vehicle with a greater GVW to result in less pavement damage than a lighter vehicle due to numbers and spacing of axles and axle groups.

3.2.1 Truck Axle Configurations

Basically there are five configurations for freight trucks described as follows (US DOT 2000):

- Single-unit trucks
- Truck-trailer combinations
- Tractor-semitrailer combinations
- Double-trailer combinations
- Triple-trailer combinations

In general, a truck is a single unit vehicle that cannot be detached from its freight bed and is composed of a single motorized device with more than two axles or more than four tires (McCracken 2005). On the other hand, a tractor is a vehicle designed preliminarily for pulling a trailer/semi-trailer that cannot be propelled on its own. Various combinations of truck fleets can be seen in Figure 3.1. Among the various configurations, the tractor-semitrailer combinations account for more than 82% of all combinations of trucks on U.S. highways (US DOT 2000).



Source: U.S. Department of Transportation (US DOT), 1996.

Figure 3.1 Illustrative Truck Fleet Configuration

Among the tractor-semitrailer combinations, the type 3-S2 is the most widely deployed for the transportation of processed meat and related products based on Bai et al. (2007). This type of truck configuration is denoted as 3-S2 where S represents semitrailer and the number following S is the number of axles of the semitrailer (US DOT 1996). The number preceding the 'S' denotes the number of axels on the tractor. The 3-S2 trucks were used for pavement damage assessment in this research.

In addition to axle configuration, pavement loadings are related to how weight is distributed from a truck. Weight distribution involves how the cargo is actually loaded onto the vehicle and how the vehicle is designed to carry its own components, such as the engine, the cab, and the trailer. The loading configuration indicates the amount of weight applied to each axle or axle group on a fully loaded vehicle (Tolliver 1994). Trucks are designed for specific loading configurations. Typically, loading configurations are described in the following manner. Numbers are given which represent the weight applied to each axle group in thousands of pounds. The numbers for specific axle groups are separated with forward slash (/) symbols (Babcock et al. 2003). A 3-S2 truck has a loading configuration of 10/35/35. This configuration means that the tractor unit applies a 10,000 pound load to the front axle, and each of two tandem axle groups under the trailer support 35,000 pounds of weight. This truck is at its maximum legal GVW at 80,000 pounds.

3.2.2 Applying Truck Configuration in Pavement Deterioration Models

Modeling of traffic loadings on pavement is important in the pavement deterioration models. Traffic loadings on pavement are directly related to weight transferred to a road surface by vehicle axles. Axle load equivalency factors are used to define the effects of different truck configurations. In addition to modeling the effects of axle passes, it is necessary to measure the serviceability of pavement segments for the estimation of pavement damage. The applications of truck and pavement characteristics are key parts in this pavement damage cost study.

The effects of different truck axle configurations on pavements are estimated by converting all axle loads to Equivalent Single Axle Loads (ESALs). An ESAL refers to the equivalent effects of a single 18,000 pound axle load applied to a pavement segment. An ESAL factor (n) is a standard reference load factor and represents the equivalent pavement impact of an axle load as compared to a single 18,000-pound axle. For example, an axle with n = 1.2 has 1.2 times the impact of a single 18,000-pound axle.

The steps in computing ESAL factors were: (1) computing the rate of pavement deterioration for the reference axle, (2) computing the rate of pavement deterioration for an axle load of interest, and (3) using the deterioration rates to compute a load equivalency factor. The ESAL factor of an axle group depends upon the type of axle (single, tandem, or triple), the load on the axle in thousands of pounds (kips), the type of pavement section (flexible or rigid), and the terminal serviceability rating of the pavement. The terminal serviceability rating is the value at which a pavement is expected to be resurfaced or reconstructed.

3.3 PAVEMENT CHARACTERISTICS DATA

The pavement section selected for this study is on highway US 50/400 between Dodge City, KS to Garden City, KS. Figure 3.2 shows the location of the highway section. This section of the highway was further divided into sub-sections or segments. Pavement characteristics data was gathered for each segment, which included functional class, pavement type, length, distress data, PSR, and structural number or slab thickness. All the original pavement data was collected from KDOT Pavement Management Information System (PMIS).

Figure 3.2 Location Map of Highway Section Under Study

3.3.1 Pavement Type, Length and Structure

There are three major types of pavements: flexible or asphalt pavements, rigid or concrete pavements, and composite pavements. Flexible pavements include the conventional types that are layered systems with better materials on top where the intensity of stress is high and inferior materials at the bottom where the intensity is low, as shown in Figure 3.3. Full-depth asphalt pavement is constructed by placing one or more layers of hot mix asphalt (HMA) directly on the subgrade or improved subgrade, as shown in Figure 3.4 (Huang 2004). Rigid pavements are constructed using Portland cement concrete (PCC) and can be classified into four types: jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), continuous reinforced concrete pavement (CRCP), and prestressed concrete pavement (PCP). Figure 3.5 shows the typical cross section of a rigid pavement. A composite pavement is composed of both HMA and PCC. The use of PCC as a bottom layer and HMA as a top layer results in an ideal pavement with the most desirable characteristics. The PCC provides a strong base and the HMA provides a smooth and nonreflective surface. This type of pavement is relatively expensive and is rarely used in new construction. Most of them are from the rehabilitation of concrete pavement using asphalt overlays.

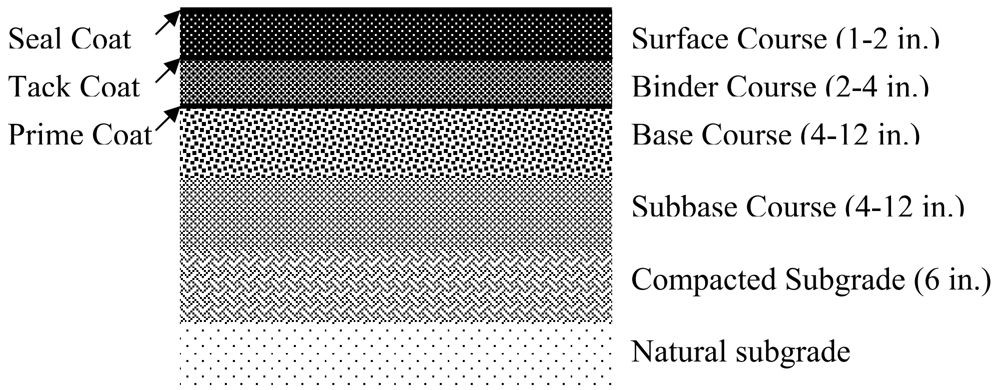


Figure 3.3 Typical Cross Section of a Conventional Flexible Pavement

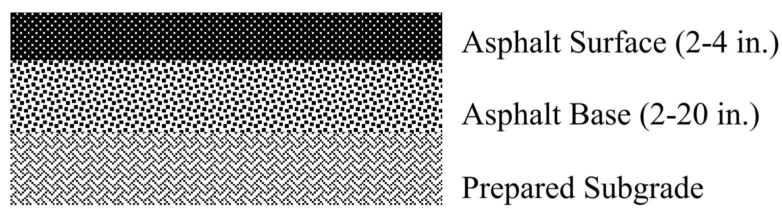


Figure 3.4 Typical Cross Section of a Full-Depth Asphalt Pavement

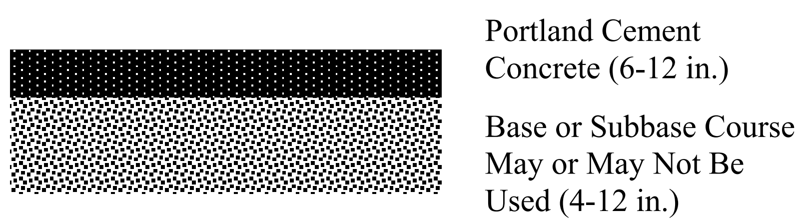


Figure 3.5 Typical Cross Section of a Rigid Pavement

Figure 3.6 shows the pavement types of the studied highway segments. In the map, PCCP refers to Portland cement concrete pavement, COMP refers to composite pavement (PCC: pavement or brick that has been overlaid with asphaltic concrete), FDBIT refers to full design bituminous pavement (designed and constructed to carry expected traffic) and PDBIT refers to partial design bituminous pavement (not designed or constructed to carry expected traffic). This map indicates that the studied pavement segments included various pavement types such as full depth flexible and composite pavements. Because the deterioration characteristics of composite pavements are close to those of flexible pavements and there are no mature pavement deterioration models existing for composite pavements, in this research all the segments were considered as the flexible pavements. Tables 3.1 - 3.3 list the detailed pavement information for each segment. There are four segments in three counties.

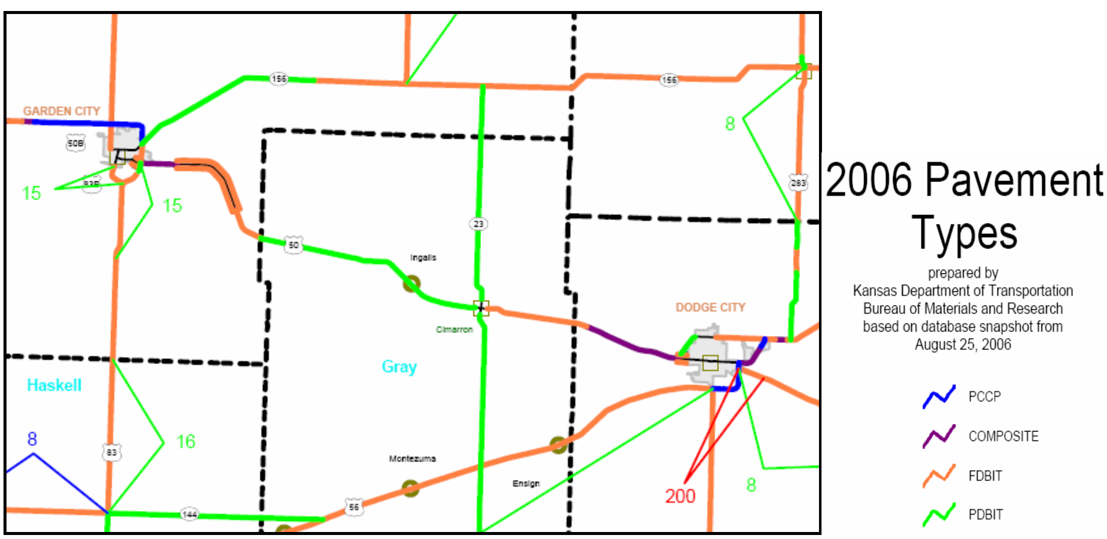


Figure 3.6 Pavement Types of the Studied Highway Segment

Table 3.1 US-50/400 Pavement Basic Data in Finney County

Segment No.	Beginning Point	Ending Point	Length	Existing Pavement Structure	
				Year	Action
1	1.4 km E Garden City	ECoL	16.3 (km) 10.13 (mile)	2005	40 mm Bit Surf SM-9.5T (PG70-28) 60 mm Bit Base SM-19A (PG70-28) 280 mm SM-19A (PG64-22) 150 mm FATSG

ECoL: East County Line

Table 3.2 US-50/400 Pavement Basic Data in Gray County

Segment No.	Beginning Point	Ending Point	Length	Existing Pavement Structure	
				Year	Action
2	WCoL	WCL Cimarron	29.2 (km) 18.14 (mile)	2004 2004 1997 1985 1985 1954-1956	38 mm Bit Surf SM12.5A(PG70-22) 38 mm Surface Recycle 41 mm BM-1B 20 mm BM-1 127 mm HRECYL 102 mm BMA-1
3	ECL Cimarron	ECoL	6.9 (km) 4.29 (mile)	2001 2001 1992 1992 1974	40 mm BM-1T 25 mm SRECYL 38 mm BM-1B 140 mm HRECYL 127 mm BC-1

WCoL/ECoL: West/East County Line
WCL/ECL Cimarron: West/East City Limits of Cimarron

Table 3.3 US-50/400 Pavement Basic Data in Ford County

Segment No.	Beginning Point	Ending Point	Length	Existing Pavement Structure	
				Year	Action
4	WCoL	Jct US-50/US-400	13.8 (km) 8.57 (mile)	2001-03 2001-03 2001 1992 1981 1981 1936	38mm BM-1T** 25mm SRECYL** 25mm Cold Mill* 38 mm HRECYL 25 mm BM-2 38 mm BM-4 178 mm PCCPAV

* 1ST 3.3km from WCoL only.
** 1ST 3.3km action performed in 2001, remainder in 2003.

The first pavement segment, from 1.4 km east of Garden city to the east Finney County line, was a full-depth flexible pavement. The performance level had remained at Level One. Based on falling weight deflectometer (FWD) data provided by KDOT, it was newly reconstructed in 2005 and the structure number was 5.40.

The second segment, from the west Gray County Line to the west city limits of Cimarron, was a full depth flexible pavement that was constructed in 1954. This section had 0.9 m bituminous and 1.5 m turf shoulders. Transverse cracking and some longitudinal cracking were the major distresses. The performance level of this segment had remained at Level One and it performed well since the rehabilitation in 1985. After an overlay in 1997, transverse cracking had reflected through in 1999 and rutting had reappeared. There was also secondary cracking along the transverse cracks. The FWD data provided by KDOT showed that the structure number for this pavement section was 3.05.

The third segment, from the east city limit of Cimarron to the east Gray county line, was a full-depth flexible design. This pavement was constructed in 1974 and had 3.0 m bituminous shoulders. The current distress in the pavement consists of rutting, fatigue cracking, and transverse cracking. The first rehabilitation action lasted nine years before the recent rehabilitation action in 2001. The performance level had remained at level one, and the IRI was at 0.80 m/km. The distress in the pavement included transverse cracking, fatigue cracking, and rutting.

The last pavement segment was composite and was originally constructed in 1936. The section had 3.0 m bituminous shoulders. By 2000, transverse cracking had reflected through and in 2001 fatigue cracking was reported. Secondary cracking along the centerline was also observed.

3.3.2 Pavement Distress Survey and PSR Performance

Serviceability of a pavement segment refers to structural and functional performance of the pavement. Pavement performances are measures of physical condition of a pavement and how well it performs for the road users. In the KDOT's PMIS, the PSR performance record of each state highway is well maintained for engineers to make better pavement management decisions. In a standard PSR datasheet, each highway section, typically divided by county lines and/or city limit, has complete data including total length, year, county number, route number, beginning and ending milepost, lane information, roughness in the right wheel path (IRIR), roughness in the left wheel path (IRIL), and PSR (calculated from IRI). KDOT has used the current method of pavement data management since 1991, thus, all the current PSR data for US-50 between Garden City and Dodge City start from 1991. This information helps to better understand the relationship between pavement PSR performance and maintenance activities.

3.3.3 Applying the Pavement data in Pavement Deterioration Models

In addition to modeling the effects of axle passes, it is necessary to measure the serviceability of pavement segments for the estimation of pavement damage. The application of pavement characteristics in pavement deterioration models played another key role in this pavement damage cost study.

Based on individual observations, the AASHO Road Test developed the present serviceability rating (PSR or *p*) as "the judgment of an observer as to the current ability of a pavement to serve the traffic it is meant to serve" (WSDOT 2003). The original AASHO Road Test PSR scores were generated by observers who drove along the test tracks and rated their ride quantitatively. This subjective scale ranges from 5 (excellent) to 0 (very Poor). As Table 3.4 depicts, the PSR considers the smoothness of the ride as well as the extent of rutting and other distresses. Modeling a decline in PSR is, to a certain extent, modeling the occurrence of individual distresses as well.

In the state of Kansas, KDOT designs for an initial PSR of 4.2, and a terminal PSR of 2.5. Subtracting the terminal PSR from the initial PSR gives the maximum life of a truck route pavement in terms of tolerable decline in PSR. This value is 1.7 for Kansas state highways.

Table 3.4 Present Serviceability Rating (PSR)

PSR	Rating	Description
4.0 - 5.0	Excellent	Only new (or nearly new) superior pavements are likely to be smooth enough and distress free (sufficiently free of cracks and patches) to qualify for this category. Most pavements constructed or resurfaced during the data year would normally be rated in this category.
3.0 - 4.0	Good	Pavements in this category, although not quite as smooth as those described above, give a first-class ride and exhibit few, if any, visible signs of surface deterioration. Flexible pavements may be beginning to show evidence of rutting and fine random cracks. Rigid pavements may be beginning to show evidence of slight surface deterioration, such as minor cracking and spalls.
2.0 - 3.0	Fair	The riding qualities of pavements in this category are noticeably inferior to those of the new pavements and may be barely tolerable for high-speed traffic. Surface defects of flexible pavements may include rutting, map cracking, and extensive patching. Rigid pavements may have a few joint fractures, faulting and/or cracking, and some pumping.
1.0 - 2.0	Poor	Pavements have deteriorated to such an extent that they affect the speed of free-flow traffic. Flexible pavement may have large potholes and deep cracks. Distress includes raveling, cracking, and rutting and occurs over 50 percent or more of the surface. Rigid pavement distress includes joint spalling, faulting, patching, cracking, and scaling and may include pumping and faulting.
0.0 - 1.0	Very Poor	Pavements are in extremely deteriorated conditions. The facility is passable only at reduced speed and considerable ride discomfort. Large potholes and deep cracks exist. Distress occurs over 75 percent or more of the surface.
Source: USDOT and FHWA, *2004 Status of the Nation's Highways, Bridges, and Transit: Conditions &Performance*, 2004		

Chapter 4

TRUCK VMT ASSOCIATED WITH THE PROCESSED BEEF AND RELATED INDUSTRIES

This chapter describes the estimation of the annual truck VMTs associated with processed beef and related industries in southwest Kansas for the studied highway section. This is an important step before implementing the pavement damage costs analysis. In this study, the highway section was divided into different pavement segments by pavement characteristics. Based on the pavement data received from KDOT, the studied highway section (US 50/400 between Garden City and Dodge City in Kansas) was divided into four pavement segments, as shown in Table 4.1.

Table 4.1 Details of Studied Pavement Segments

Pavement Segment	Description	Length (Miles)
PS 1	1.4 km east of Garden city, KS to East Finney County Line	10.13
PS 2	West Gray County Line to West City Limits of Cimarron, KS	18.14
PS 3	East City Limits of Cimarron, KS to the East Gray County Line	4.29
PS 4	West Ford County Line to Junction of US-50 and US-400	8.57
PS 1-4	Total	41.13

As discussed in Bai et al. (2007), the transporting sequence of the Kansas meat industry was shown in Figure 2.1. This sequence included six major components as listed following:

1. Transporting feeder cattle to feed yards in southwest Kansas;
    - 1(a) Transporting feeder cattle from outside of southwest Kansas to 24 county centroids (in southwest Kansas area) through major highways;
    - 1(b) Transporting feeder cattle from each county centroid to each feed yard through local roadways;
2. Transporting feed grain to feed yards in southwest Kansas;
3. Transporting finished cattle to meat processing plants in southwest Kansas;
    - 3(a) Transporting cattle from each feed yard to each county centroid through local roadways;

3(b) Transporting cattle from 24 county centroids (in southwest Kansas area) to the four meat processing plants through major highways;

3(c) Transporting cattle from outside of southwest Kansas to the four meat processing plants through major highways;

4. Transporting boxed beef to customers in the United States;
5. Transporting meat byproducts;
6. Transporting boxed beef to overseas customers.

To estimate the processed beef and related truck traffic in southwest Kansas, the origins and destinations of each stage in the movement of cattle and grain were identified first. Based on the identified origins and destinations, the beef-related truck traffic was then distributed to the major highways in southwest Kansas area using TransCAD software. Routes were selected based on least distance, giving priority to the state highway system, which provides better serviceability. Figure 4.1 shows the highway network used in the truck travel path analysis. Figure 4.2 is the flowchart showing the procedure of the estimation of annual truck VMTs associated with processed beef and related industries. Detailed descriptions are provided in the following sections.

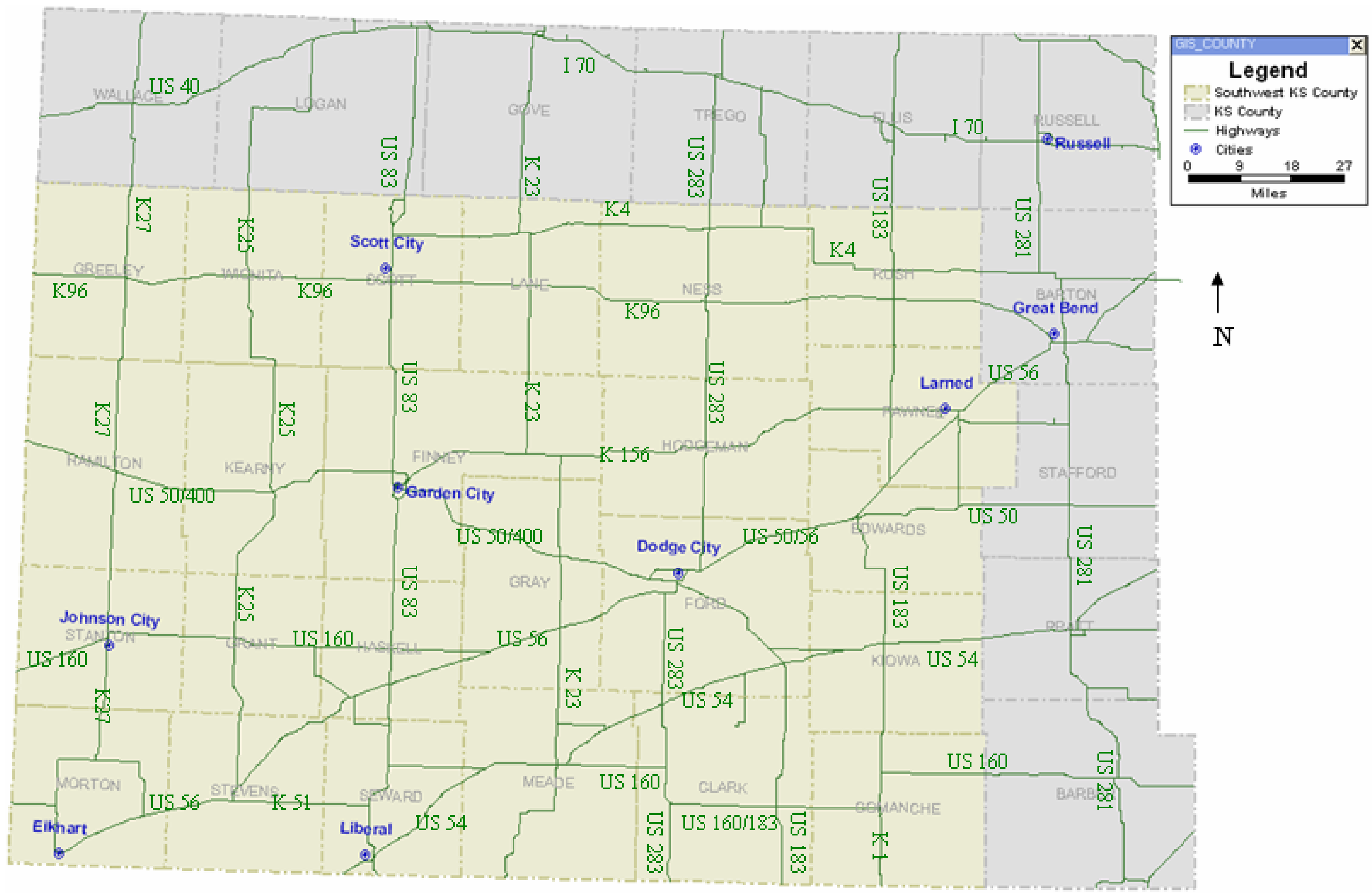


Figure 4.1 Southwest Kansas Highway Map (Source: KDOT 2005)

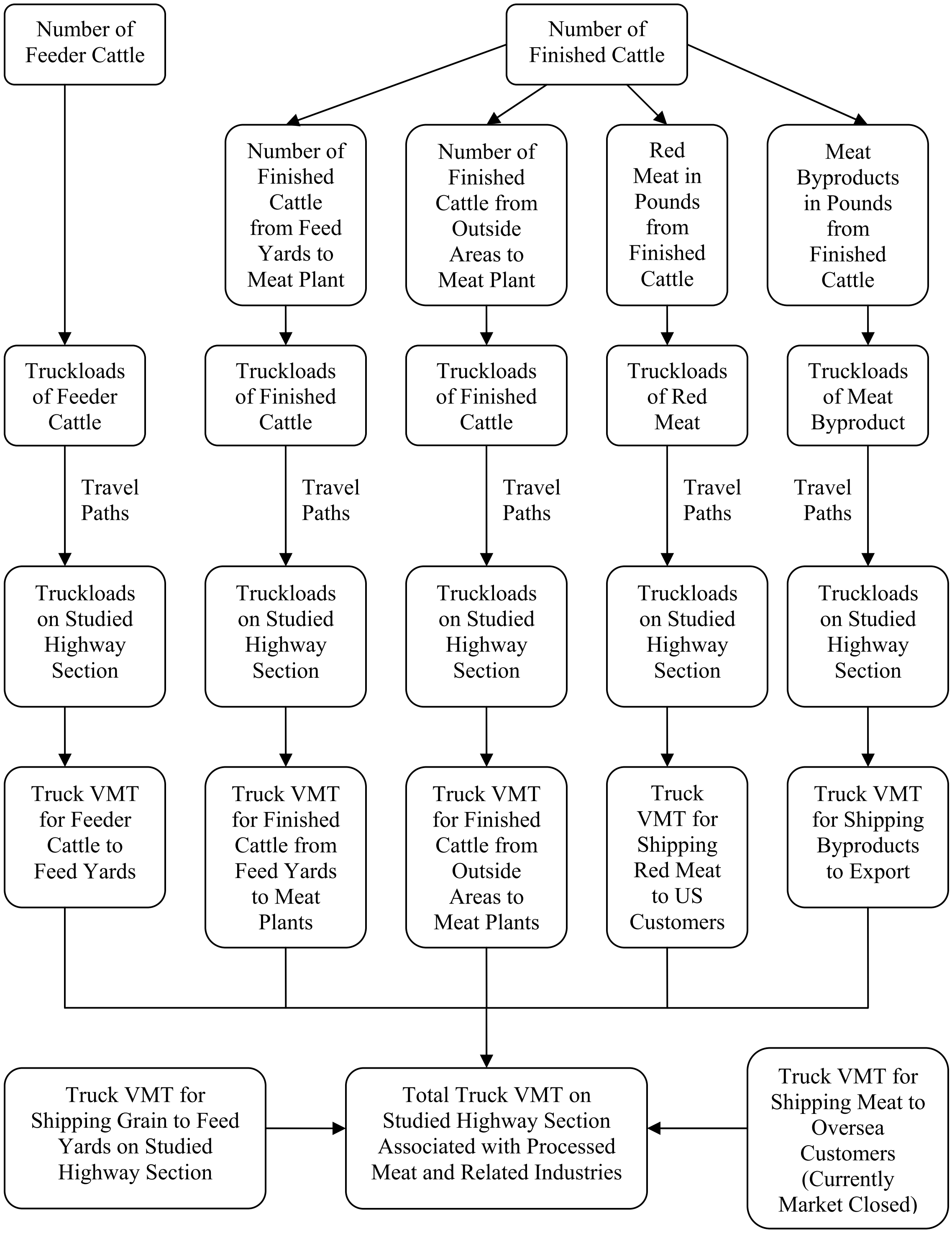


Figure 4.2 Flowchart Showing the Procedure of the Estimation of Annual Truck VMT Associated with Processed Beef and Related Industries

4.1 TRUCK VMT FOR TRANSPORTING FEEDER CATTLE TO FEED YARDS

4.1.1 Truck Travel Paths for Transporting Feeder Cattle to Feed Yards

The cattle in southwest Kansas were assumed to be transported to the region for feeding from other states and/or other parts of Kansas. As shown in Figure 1.2, there were approximately 369 feed yards located within the 24 counties of the southwest Kansas region. Figure 4.3 shows the 24 counties of the analysis area with centroids and the major highways. For this analysis, a centroid was defined as the aggregation of the feed yards within a county. Additionally, a centroid for each county must be located on a highway. The truck travel paths for transporting feeder cattle to feed yards were estimated based on two steps: 1) from entry points of the southwest Kansas boundary to county centroids, and 2) from the centroid of a county to the feed yards within this same county in the study area.

To estimate the truck travel paths for transporting feeder cattle to feed yards from entry points of the southwest Kansas boundary to county centroids, the first step was to determine origins and destinations involved in this transportation. Since cattle came from different origins outside of southwest Kansas, there was a need to define entry points on the southwest Kansas boundaries. The previous research estimated that there were 3,721,050 cattle on feed per year in southwest Kansas counties and 30% of them came from the east, south, and north, respectively, and the remaining 10% of the cattle came from the west (Bai et al. 2007). These proportions had to be allocated to each county, which must also match the number of feeder cattle per year for the individual county. To facilitate the allocation, the southwest Kansas region was divided into four zones: Zone I, Zone II, Zone III and Zone IV, as shown in Figure 4.4. Bai et al. (2007) developed the allocation procedure and described it in their final report. In summary, the cattle from the east boundary, through three entries on highways 54, 56 and 160, were allocated to the counties in the east including Zones I and II. The cattle from the north boundary, through three entries on highways 83, 183, and 283 were allocated in Zones I and IV. The next cycle of allocating cattle began with cattle coming from the south boundary, through the entries on highways 54, 56, 183 and 283, and then the cattle coming from west boundary through the entries on highways 50/400 and 160. Cattle from the south and the west were allocated in Zones II and III, and Zones III and IV, respectively.

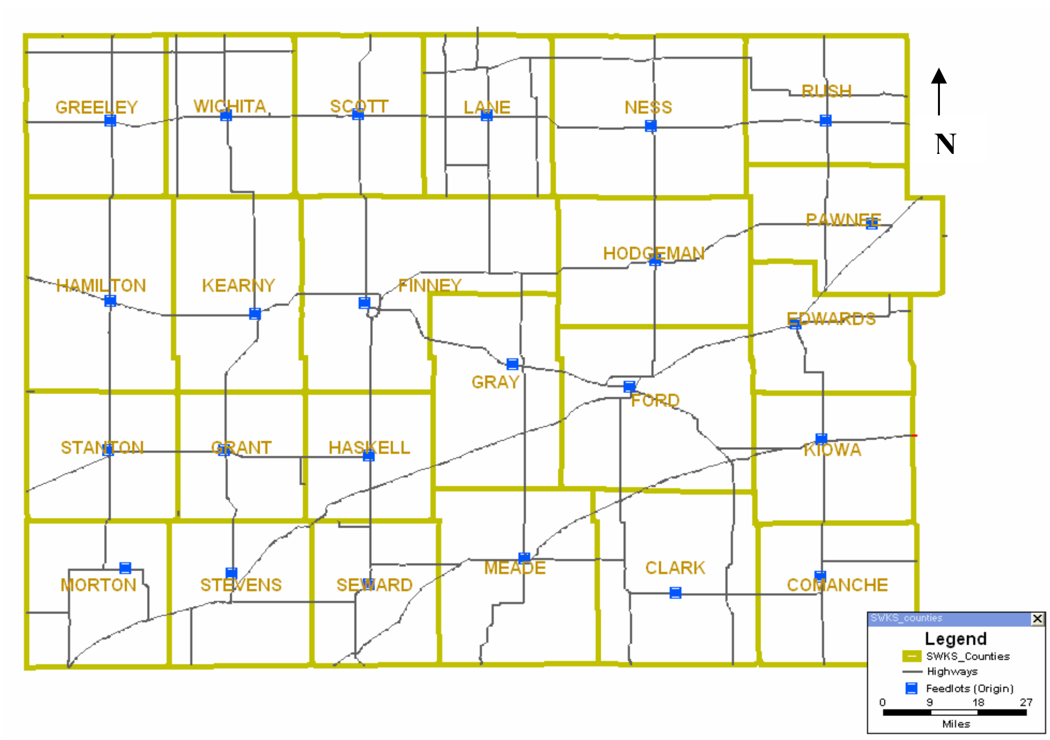


Figure 4.3 24 Counties in the Analysis Area, Their Centroids, and Major Highways

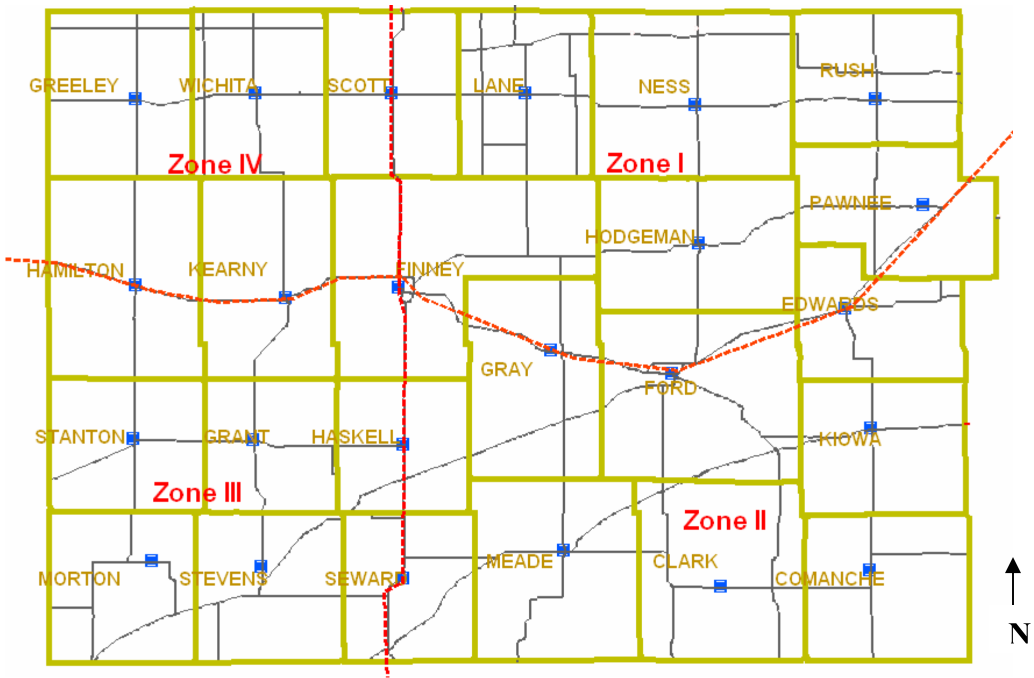


Figure 4.4 Zone Analysis for Allocating Cattle in Southwest Kansas

Table 4.2 summarizes the feeder cattle allocation sequence and the highway entrances. In the Highway Entry Point column of the table, the first letter of each entry point highway represents the direction, and the following number represents the highway number. For instance, E54 represents highway 54 in the east boundary of southwest Kansas.

Appendix I lists the shortest-path analysis results for transporting feeder cattle from county centroids to feed yards in each of the studied counties. Results showed that all the travel paths were on local roads and thus they were not considered in this study.

Table 4.2 Sequence for Allocating Feeder Cattle in Each County

Total Feeder Cattle in Each Direction	**County in Sequence**	**Highway Entry Point**	**Number of Feeder Cattle Allocated to Each County per Year**
1,116,315 (East)	Rush	E160, E54, E56	3,482
	Pawnee	E160, E54, E56	165,800
	Edwards	E160, E54, E56	62,506
	Kiowa	E160, E54, E56	11,996
	Comanche	E160, E54, E56	1,600
	Ness	E160, E54, E56	0
	Hodgeman	E160, E54, E56	65,800
	Ford	E160, E54, E56	240,200
	Clark	E160, E54, E56	67,800
	Lane	**E160, E54,** E56	**71,016**
	Finney	**E160, E54,** E56	**426,115**
1,116,315 (North)	Finney	N183, N283, N83	91,885
	Scott	N183, N283, N83	415,400
	Wichita	N183, N283, N83	241,852
	Greeley	N183, N283, N83	21,400
	Hamilton	N183, N283, N83	131,400
	Kearny	N183, N283, N83	119,600
	Gray	**N183**, N283, **N83**	**94,778**
1,116,315 (South)	**Gray**	**S183**, S283, S54, S56	**204,222**
	Meade	S183, S283, S54, S56	37,000
	Seward	S183, S283, S54, S56	163,480
	Stevens	S183, S283, S54, S56	61,666
	Haskell	S183, S283, S54, S56	595,200
	Grant	S183, S283, S54, S56	54,747
372,105 (West)	Grant	W160, W50/400	283,517
	Stanton	W160, W50/400	85,264
	Morton	W160, W50/400	3,324
Total			3,721,050

4.1.2 Truckloads for Transporting Feeder Cattle to Feed Yards

4.1.2.1 Truckloads for Transporting Feeder Cattle from the East

Figure II.1 in Appendix II presents the travel paths from highway entry points E54, E56 and E160 at the east boundary to eleven county centroids including Rush, Pawnee, Edwards, Kiowa, Comanche, Ness, Hodgeman, Ford, Clark, Lane, and

Finney. The results showed that the travel paths from E54 and E160 to Finney County passed through all the studied pavement segments 1 to 4, and the travel paths from E54 and E160 to Lane County passed through a portion of the studied highway section, from Dodge City to Cimarron, KS, or the pavement segments 3 and 4. None of the travel paths from E50 to all eleven counties were on studied pavement segments. Similarly, travel paths from E56 and E160 to the other nine counties, except for Finney and Lane, did not pass through the studied pavement segments.

Table 4.2 shows that every year, 426,115 feeder cattle were transported to Finney County through three highway entry points at the east boundary. A semi-truck can hold nearly 75 feeder cattle, each weighing approximately 675 lbs, and 45 finished cattle, each weighing approximately 1,200 lbs (Bai et al. 2007). Assuming the feeder cattle from the east were transported equally from three highway entries, the annual truckloads for cattle transportation from E54 and E160 to Finney were estimated as:

$$\text{Annual truckloads} = \frac{426{,}115\,cattle \times {}^{2}\!/_{3}}{75\,cattle/truck} = 3{,}788 \text{ trucks}$$

Table 4.2 also indicates that 71,016 feeder cattle were allocated to Lane County from three entry points. Therefore, the annual truckloads were:

$$\text{Annual truckloads} = \frac{71{,}016\,cattle \times {}^{2}\!/_{3}}{75\,cattle/truck} = 631 \text{ trucks}$$

4.1.2.2 Truckloads for Transporting Feeder Cattle from the North

Figure II.2 in Appendix II shows that the travel paths from three highway entry points N83, N183 and N283 in the north boundary to seven counties, Finney, Scott, Wichita, Greeley, Hamilton, Kearny, and Gray. The results showed that the travel path from N83 to Gray County passed through studied pavement segments 1 and 2, and the travel path from N183 to Gray County passed through segments 3 and 4. None of travel paths from N283 to all seven counties were on the studied pavement segments. Travel paths from N83 and N183 to other six counties, except for Gray, were not on studied pavement segments. Thus, the annual truckloads were estimated as:

$$\text{Annual truckloads (PS 1-2)} = \frac{94{,}778 \times \frac{1}{3}}{75} = 421 \text{ trucks}$$

$$\text{Annual truckloads (PS 3-4)} = \frac{94{,}778 \times \frac{1}{3}}{75} = 421 \text{ trucks}$$

4.1.2.3 Truckloads for Transporting Feeder Cattle from the South and West

Figure II.3 in Appendix II shows that the travel paths from four highway entry points S183, S283, S54 and S56 in the south boundary to six counties, which are Gray, Meade, Seward, Stevens, Haskell and Grant. The results showed that the travel path from S183 to Gray County passed through segments 3 and 4. Travel paths from S183 to the other five counties were not on the studied pavement segments. In addition, none of travel paths from S283, S54, and S56 to all six counties passed through the studied pavement segments. Thus, the annual truckloads were estimated as:

$$\text{Annual truckloads (PS 3-4)} = \frac{204{,}222 \times \frac{1}{3}}{75} = 908 \text{ trucks}$$

According to the shortest path results showed in Figure II.4 (see Appendix II), there were no cattle shipments on the studied highway section transporting feeder cattle from two entry points on the west boundary.

4.1.3 Truck VMT for Transporting Feeder Cattle to Feed Yards

Table 4.3 summarizes the total annual truckloads and truck VMT estimated on the studied pavement segments for transporting feeder cattle to feed yards.

Table 4.3 Total Truckloads and Truck VMT for Transporting Feeder Cattle to Feed Yards

Pavement Segment (PS)	Length of Pavement Segments (miles)	Annual Truckloads					Annual Truck VMT
		East	North	South	West	Total	
PS 1	10.13	3,788	421	0	0	4,209	42,637
PS 2	18.14	3,788	421	0	0	4,209	76,351
PS 3	4.29	4,419	421	908	0	5,748	24,659
PS 4	8.57	4,419	421	908	0	5,748	49,260

4.2 TRUCK VMT FOR TRANSPORTING GRAINS TO FEED YARDS

Results of previous research showed that the quantities of feed grain in most counties were sufficient to support their demands (Bai et al. 2007). However, some counties did receive feed grain from other states and/or other regions of Kansas. Because the quantities of feed grain received from other states and/or other regions of Kansas used for feeder cattle in southwest Kansas counties were unknown, previous researchers assumed that all counties in the studied area had sufficient feed grain for their feed yards. With this assumption, the county centroids in this analysis were also considered as grain elevator stations that distributed the feed grain to each feed yard in the respective county.

Appendix I shows the shortest path results for transporting grain from county centroids to feed yards in each respective county and these paths are the same as those for transporting feeder cattle. None of the paths used by feed grain transportation were on major highways. Therefore, no truck VMTs associated with the grain transportation were considered for the pavement damage analysis.

4.3 TRUCK VMT FOR TRANSPORTING FINISHED CATTLE TO MEAT PROCESSING PLANTS

Based on USDA data, there were 7,321,400 cattle slaughtered in Kansas in 2005. According to the data collected from the four largest meat processing facilities in the southwest Kansas region, approximately 23,600 cattle were slaughtered everyday. In addition, about 4,000 cattle per day were slaughtered in another large meat processing facility in Kansas, but it was not in the southwest Kansas region. Thus, approximately, a total of 27,600 cattle were killed in Kansas every day. The number of cattle slaughtered in the southwest Kansas region in 2005 was estimated proportionally as follows (Bai et al. 2007):

Number of cattle slaughtered = 7,321,400 x (23,600 / 27,600) = 6,260,330

In 2005, there were 3,721,050 cattle fed in southwest Kansas area. If assume that all cattle fed in southwest Kansas were slaughtered in the southwest Kansas, then, 2,539,280 (6,260,330 – 3,721,050) additional cattle would have to have been transported into southwest Kansas from other states and/or other parts of Kansas (Bai et al. 2007). The cattle from both inside and outside of southwest Kansas were then delivered to the four major meat processing plants including Excel Corporation in Dodge City, National Beef in Dodge City, National Beef in Liberty, and Tyson Fresh Meats in Holcomb. Two steps were involved in the calculation of the truck VMT for transporting cattle to four meat processing facilities in southwest Kansas: 1) estimating the truck VMT generated by transporting cattle from feed yards in southwest Kansas to the meat processing facilities, which included transporting cattle from feed yards to county centroids and then transporting from the county centroids to the four meat plants; and 2) estimating the truck VMT for transporting cattle from other states and/or other parts of Kansas to meat processing facilities in southwest Kansas.

4.3.1 Truck VMT for Transporting Cattle from Feed Yards in Southwest Kansas to Meat Processing Plants

Appendix I shows the same shortest paths for transporting finished cattle from feed yards to county centroids as those for transporting feeder cattle from county centroids to feed yards with reversed origins and destinations. Since those local travel paths had no impact on the highway section used for this pavement damage analysis, they are not discussed further.

After the finished cattle were transported to the county centroids, they were then shipped to the four major meat processing facilities in the southwest Kansas region for slaughter. To simplify the distribution process, it was assumed that an average of 25% of the annual truckloads from each county were distributed to each of the four major meat processing facilities. Thus, the annual truckloads from each of the county centroids to each of the four meat processing facilities in the southwest Kansas region were calculated using the following formula.

Annual truckloads from a county centroid to a meat processing facility
= 25% x annual truckloads of a county

In addition to the annual truckloads from each county centriod to the four meat processing facilities, there was a need to find out the truck travel paths from each county centroid to each of the four meat processing facilities in order to estimate the VMT on the studied highway pavement segments. These paths were determined using TransCAD software based on the shortest path method and the results are shown in Appendix III. In the TransCAD analyses, the origins were twenty-four county centroids and the destinations were four meat processing plants.

Annual truckloads for transporting finished cattle from each county to each meat processing plant were determined in previous research and results were shown in Table 4.4 to 4.7. Based on truck travel paths shown in figures of Appendix III, Table 4.8 was developed to summarize the truckloads and identify the impacted pavement segments. Note that none of the trucks transporting cattle to the National

Beef Liberal plant utilized the studied highway section, thus, this plant was not included in Table 4.8.

Table 4.4 Daily & Annual Truck VMT for Transporting Finished Cattle from Southwest Kansas County Centroids to Excel Corporation (Bai et al. 2007)

No.	County	Annual Truckloads	Total Distance Traveled (miles)	Annual VMT	Daily VMT
1	Clark	377	47.18	17,787	49
2	Comanche	9	71.27	641	2
3	Edwards	347	39.38	13,665	37
4	Finney	2,878	60.45	173,975	477
5	Ford	1,334	4.86	6,483	18
6	Grant	1,879	112.16	210,749	577
7	Gray	1,661	27.55	45,761	125
8	Greeley	119	141.96	16,893	46
9	Hamilton	730	111.56	81,439	223
10	Haskell	3,307	85.42	282,484	774
11	Hodgeman	366	31.69	11,599	32
12	Kearny	664	84.24	55,935	153
13	Kiowa	67	45.56	3,053	8
14	Lane	394	78.59	30,964	85
15	Meade	205	41.88	8,585	24
16	Morton	18	132.34	2,382	7
17	Ness	0	56.93	0	0
18	Pawnee	921	68.69	63,263	173
19	Rush	19	78.9	1,499	4
20	Scott	2,308	95.76	220,990	605
21	Seward	908	75.34	68,409	187
22	Stanton	474	134.03	63,530	174
23	Stevens	343	108.82	37,325	102
24	Wichita	1,344	120.23	161,589	443
Totals		20,672		1,579,000	4,325

Table 4.5 Daily & Annual Truck VMT for Transporting Finished Cattle from Southwest Kansas County Centroids to National Beef in Dodge City (Bai et al. 2007)

No.	County	Annual Truckloads	Total Distance Traveled (miles)	Annual VMT	Daily VMT
1	Clark	377	49.79	18,771	51
2	Comanche	9	66.71	600	2
3	Edwards	347	34.77	12,065	33
4	Finney	2,878	55.84	160,708	440
5	Ford	1,334	0.25	334	1
6	Grant	1,879	107.55	202,086	554
7	Gray	1,661	22.94	38,103	104
8	Greeley	119	137.35	16,345	45
9	Hamilton	730	106.95	78,074	214
10	Haskell	3,307	80.81	267,239	732
11	Hodgeman	366	27.08	9,911	27
12	Kearny	664	79.63	52,874	145
13	Kiowa	67	40.99	2,746	8
14	Lane	394	73.98	29,148	80
15	Meade	205	44.49	9,120	25
16	Morton	18	134.95	2,429	7
17	Ness	0	52.32	0	0
18	Pawnee	921	64.08	59,018	162
19	Rush	19	74.29	1,412	4
20	Scott	2,308	91.15	210,351	576
21	Seward	908	77.95	70,779	194
22	Stanton	474	129.42	61,345	168
23	Stevens	343	111.43	38,220	105
24	Wichita	1,344	115.62	155,393	426
Totals		20,672		1,497,071	4,103

Table 4.6 Daily & Annual Truck VMT for Transporting Finished Cattle from Southwest Kansas County Centroids to National Beef in Liberal (Bai et al. 2007)

No.	County	Annual Truckloads	Total Distance Traveled (miles)	Annual VMT	Daily VMT
1	Clark	377	72.08	27,174	74
2	Comanche	9	102.12	919	3
3	Edwards	347	117.13	40,644	111
4	Finney	2,878	69.3	199,445	546
5	Ford	1,334	82.61	110,202	302
6	Grant	1,879	63.11	118,584	325
7	Gray	1,661	75.72	125,771	345
8	Greeley	119	147.06	17,500	48
9	Hamilton	730	112.91	82,424	226
10	Haskell	3,307	39.64	131,089	359
11	Hodgeman	366	109.44	40,055	110
12	Kearny	664	91.04	60,451	166
13	Kiowa	67	99.84	6,689	18
14	Lane	394	120.79	47,591	130
15	Meade	205	37.87	7,763	21
16	Morton	18	62.94	1,133	3
17	Ness	0	134.69	0	0
18	Pawnee	921	146.44	134,871	370
19	Rush	19	156.65	2,976	8
20	Scott	2,308	104.72	241,668	662
21	Seward	908	15.57	14,138	39
22	Stanton	474	84.99	40,285	110
23	Stevens	343	39.99	13,717	38
24	Wichita	1,344	129.19	173,631	476
Totals		20,672		1,638,720	4,490

Table 4.7 Daily & Annual Truck VMT for Transporting Finished Cattle from Southwest Kansas County Centroids to Tyson Fresh Meats in Holcomb (Bai et al. 2007)

No.	County	Annual Truckloads	Total Distance Traveled (miles)	Annual VMT	Daily VMT
1	Clark	377	112.39	42,371	116
2	Comanche	9	129.97	1,170	3
3	Edwards	347	96.95	33,642	92
4	Finney	2,878	7.53	21,671	59
5	Ford	1,334	63.02	84,069	230
6	Grant	1,879	44.28	83,202	228
7	Gray	1,661	40.33	66,988	184
8	Greeley	119	77.84	9,263	25
9	Hamilton	730	43.68	31,886	87
10	Haskell	3,307	37.19	122,987	337
11	Hodgeman	366	63.5	23,241	64
12	Kearny	664	16.36	10,863	30
13	Kiowa	67	104.26	6,985	19
14	Lane	394	60.75	23,936	66
15	Meade	205	78.18	16,027	44
16	Morton	18	93.16	1,677	5
17	Ness	0	88.66	0	0
18	Pawnee	921	106.25	97,856	268
19	Rush	19	116.45	2,213	6
20	Scott	2,308	38.96	89,910	246
21	Seward	908	61.26	55,624	152
22	Stanton	474	66.16	31,360	86
23	Stevens	343	67.98	23,317	64
24	Wichita	1,344	57.62	77,441	212
Totals		20,672		957,699	2,623

Table 4.8 Truckloads for Transporting Cattle from Counties to Meat Plants

County (Origin)	Meat Processing Plant (Destination)	Truckloads	Impacted Pavement Segments (PS)
Finney	Excel Corporation, Dodge City	2,878	1, 2, 3, 4
Grant		1,879	1, 2, 3, 4
Gray		1,661	3, 4
Greeley		119	1, 2, 3, 4
Hamilton		730	1, 2, 3, 4
Haskell		3,307	1, 2, 3, 4
Kearny		664	1, 2, 3, 4
Lane		394	3, 4
Scott		2,308	1, 2, 3, 4
Stanton		474	1, 2, 3, 4
Wichita		1,344	1, 2, 3, 4
Finney	National Beef, Dodge City	2,878	1, 2, 3, 4
Grant		1,879	1, 2, 3, 4
Gray		1,661	3, 4
Greeley		119	1, 2, 3, 4
Hamilton		730	1, 2, 3, 4
Haskell		3,307	1, 2, 3, 4
Kearny		664	1, 2, 3, 4
Lane		394	3, 4
Scott		2,308	1, 2, 3, 4
Stanton		474	1, 2, 3, 4
Wichita		1,344	1, 2, 3, 4
Comanche	Tyson Fresh Meats, Holcomb	9	1, 2, 3, 4
Clark		377	1, 2
Edwards		347	1, 2, 3, 4
Ford		1,334	1, 2, 3, 4
Gray		1,661	1, 2
Kiowa		67	1, 2, 3, 4
Meade		205	1, 2

Thus, the total truckloads and truck VMT for transporting finished cattle from counties in southwest Kansas to the four meat processing plants on each study pavement segment were estimated as:

$$\text{Annual Truckloads (PS 1)} = \sum_{i=1}^{n} \text{ truckloads from each county} = 31{,}406$$

$$\text{Annual Truckloads (PS 2)} = \sum_{i=1}^{n} \text{ truckloads from each county} = 31{,}406$$

$$\text{Annual Truckloads (PS 3)} = \sum_{i=1}^{n} \text{ truckloads from each county} = 33{,}274$$

$$\text{Annual Truckloads (PS 4)} = \sum_{i=1}^{n} \text{ truckloads from each county} = 33{,}274$$

$$\text{Annual Truck VMT (PS 1)} = 31{,}406 \times 10.13 \text{ miles} = 318{,}143$$

$$\text{Annual Truck VMT (PS 2)} = 31{,}406 \times 18.14 \text{ miles} = 569{,}705$$

$$\text{Annual Truck VMT (PS 3)} = 33{,}274 \times 4.29 \text{ miles} = 142{,}745$$

$$\text{Annual Truck VMT (PS 4)} = 33{,}274 \times 8.57 \text{ miles} = 285{,}158$$

4.3.2 Truck VMT for Transporting Cattle from Outside of Southwest Kansas to Meat Processing Plants

As discussed in the previous section, based on the 2005 data, 2,539,280 cattle were transported annually into southwest Kansas from other states and/or other parts of Kansas to the four major meat processing facilities. In the previous project, researchers made the following assumptions about the numbers of cattle coming from different directions: 70% of the cattle came from the south and 10% of the cattle came from each of the north, east, and west. Based on these assumptions, the number of finished cattle coming from the south was estimated as 1,777,496 (70% x 2,539,280) and the number of the finished cattle coming the north, east, and west was 253,928 (10% x 2,539,280) each direction.

It was further assumed that cattle from each direction were distributed to each of the four meat processing facilities evenly. Thus, the annual number of cattle coming from each direction to each of the meat processing facilities in the southwest Kansas region was calculated using the following formula:

Annual number of cattle from one direction to a meat processing facility

= 25% x Annual number of finished cattle from a certain direction

Knowing the numbers of cattle from each direction to the meat processing facilities and the number of finished cattle per truck (45 finished cattle per truck); the required truckloads for transporting cattle were calculated as follows:

Annual truckloads from one direction to a meat processing facility

= Annual number of finished cattle to a meat processing facility (single direction)/45

Table 4.9 lists the annual truckloads for transporting finished cattle from other states and/or other areas of Kansas to the four meat processing plants in southwest Kansas.

With information on the total truckloads from each highway entry point to the meat processing plants the shortest travel paths from entry points on the southwest Kansas boundary to the four meat processing facilities were determined using TransCAD. These shortest paths are presented in Appendix IV. In addition, the truck traffic due to transporting cattle on the studied highway section was also estimated assuming that the finished cattle from each direction were equally distributed at the highway entries on the boundary on that direction. Table 4.10 summarizes the results of the truckloads passing through the studied pavement segments for transporting finished cattle from outside southwest Kansas to four meat processing plants. Note that none of the trucks transporting cattle to the National Beef Liberal plant utilized the studied highway section, thus, this plant was not included in Table 4.10.

Table 4.9 Annual Truckloads for Transporting Finished Cattle from Outside of Southwest Kansas to Four Meat processing Plants

No.	**Destination**	**Entry Point on Highway**	**Annual Truckloads in Each Direction**			
			East	**South**	**West**	**North**
1	Excel Corporation, Dodge City	E54, E160, E56, N183, N283, N83, W160, W50, S54, S283, S56, S183	1,410	9,874	1,410	1,410
2	National Beef, Dodge City	E54, E160, E56, N183, N283, N83, W160, W50, S54, S283, S56, S183	1,410	9,874	1,410	1,410
3	National Beef, Liberal	E54, E160, E56, N183, N283, N83, W160, W50, S54, S283, S56, S183	1,410	9,874	1,410	1,410
4	Tyson Fresh Meats, Holcomb	E54, E160, E56, N183, N283, N83, W160, W50, S54, S283, S56, S183	1,410	9,874	1,410	1,410
Total			5,640	39,496	5,640	5,640

Table 4.10 Truckloads for Transporting Cattle from Outside to Meat Plants

Entry Point (Origin)	**Meat Processing Plant (Destination)**	**Truckloads**	**Impacted Pavement Segments (PS)**
W50	Excel Corporation, Dodge City	1,470 x ½ = 705	1, 2, 3, 4
W160		1,470 x ½ = 705	1, 2, 3, 4
N83		1,410 x 1/3 = 470	1, 2, 3, 4
W50	National Beef, Dodge City	1,470 x ½ = 705	1, 2, 3, 4
W160		1,470 x ½ = 705	1, 2, 3, 4
N83		1,410 x 1/3 = 470	1, 2, 3, 4
E54	Tyson Fresh Meats, Holcomb	1,410 x 1/3 = 470	1, 2, 3, 4
E160		1,410 x 1/3 = 470	1, 2, 3, 4
S183		9,874 x 1/4 = 2,469	1, 2, 3, 4
S283		9,874 x 1/4 = 2,469	1, 2

Therefore, the total truckloads and truck VMT for transporting finished cattle from outside of southwest Kansas to the four meat processing plants on each studied pavement segment can be computed by the following formulas:

$$\text{Annual Truckloads (PS 1)} = \sum_{i=1}^{n} \text{ truckloads from each entry point} = 9{,}638$$

$$\text{Annual Truckloads (PS 2)} = \sum_{i=1}^{n} \text{ truckloads from each entry point} = 9{,}638$$

$$\text{Annual Truckloads (PS 3)} = \sum_{i=1}^{n} \text{ truckloads from each entry point} = 7{,}169$$

$$\text{Annual Truckloads (PS 4)} = \sum_{i=1}^{n} \text{ truckloads from each entry point} = 7{,}169$$

Annual Truck VMT (PS 1) = $9{,}638 \times 10.13$ miles = 97,633

Annual Truck VMT (PS 2) = $9{,}638 \times 18.14$ miles = 174,833

Annual Truck VMT (PS 3) = $7{,}169 \times 4.29$ miles = 30,755

Annual Truck VMT (PS 4) = $7{,}169 \times 8.57$ miles = 61,438

Table 4.11 presents the total annual truckloads and truck VMT for transporting finished cattle to meat processing plants.

Table 4.11 Total Truckloads and Truck VMT for Transporting Cattle to Meat Plants

Pavement Segment (PS)	Annual Truckloads			Annual Truck VMTs		
	Southwest	Outside	Total	Southwest	Outside	Total
PS 1	31,406	9,638	41,044	318,143	97,633	415,776
PS 2	31,406	9,638	41,044	569,705	174,833	744,538
PS 3	33,274	7,169	40,443	142,745	30,755	173,500
PS 4	33,274	7,169	40,443	285,158	61,438	346,596

4.4 TRUCK VMT FOR TRANSPORTING MEAT TO U.S. CUSTOMERS

The processed meat (boxed beef) from each of the four meat processing facilities is transported to various customers in the United States. In the previous research, researchers assumed that processed meat was first distributed to customers in six large cities in the U.S. including Atlanta, Chicago, Dallas, Los Angeles, New York, and Phoenix. Then meat was distributed from these large cities to customers in small satellite cities and towns. The researchers made this assumption based on the following two reasons (Bai et al. 2007):

1. Based on interviews conducted during the site visits, researchers came to a consensus that these six cities represented the biggest cities in the east, south, west, and north directions from where the processed meat was mostly distributed to other small cities and towns.
2. The same highways in the southwest Kansas region would be used to transport the processed meat to customers in the U.S. even if the final destinations were not in these six cities.

With the above assumption, the calculation of truck VMT on the studied highway section for transporting meat to U.S. customers would be equivalent to the determination of truck VMT generated by transporting meat to the six U.S. cities. To calculate the VMT, the travel paths from the respective meat processing facilities to the six cities were assigned to the major highways first using TransCAD software based on the shortest path criteria. The results are listed in the maps and tables in

Appendix V. As indicated in the maps, only the travel path of transporting beef from Tyson at Holcomb, KS to Dallas, TX passed through the studied pavement segments.

To estimate the truckloads for transporting beef from Tyson to Dallas, the annual cattle slaughtered in this meat processing plant was estimated first. As mentioned previously, based on the 2005 data, an annual total of 6,260,330 cattle were slaughtered in the four major meat processing plants in the southwest Kansas region. Considering the similar scale of the four plants, it is reasonable to assume that a quarter of the finished cattle were slaughtered in Tyson. Thus, the annual total number of finished cattle slaughtered in Tyson in Dodge City is approximately equal to 1, 565,083 (6,260,330 x 25%).

Based on results of previous research, the average weight of cattle at the time of slaughtering is approximately 1,200 lbs., with about 720 pounds (60%) of red meat and 480 pounds (40%) of byproducts (Bai et al. 2007). In addition, a truck can carry a total of 42,000 pounds of boxed beef per load. Therefore, the annual quantity of red meat originating at Tyson is:

Annual quantity of red meat from Tyson

= Total annual number of finished cattle coming to Tyson x 720 pounds

= 1,565,083 finished cattle x 720 pounds

= 1,126,859,760 pounds of red meat

The annual number of truckloads for transporting boxed beef produced at Tyson can be calculated as:

Annual Truckloads

= Annual quantity of red meat from Tyson / truck capacity

= 1,126,859,760 / 42,000

= 26,830 truckloads of boxed meat

Thus, it was estimated that there were approximately 26,830 truckloads of boxed beef produced by Tyson based on 2005 data. It was further assumed that the quantity of boxed beef from each of the meat processing facilities (origins) was equally distributed among the six large cities (destinations). In other words, about 16.67% (1/6 =16.67%) of the annual number of truckloads of boxed beef originating at each meat processing facility was distributed to each of the six cities. Therefore, the annual number of truckloads shipped from Tyson to Dallas, TX is as follows:

Annual number of truckloads from Tyson to Dallas, TX

= 16.67% x 26,830

= 4,473 truckloads of boxed meat

Since these truckloads travel through all four studied pavement segments, the annual truck VMTs on each segment are:

Annual Truck VMT on PS 1 = $4{,}473 \times 10.13$ miles = 45,312

Annual Truck VMT on PS 2 = $4{,}473 \times 18.14$ miles = 81,140

Annual Truck VMT on PS 3 = $4{,}473 \times 4.29$ miles = 19,189

Annual Truck VMT on PS 4 = $4{,}473 \times 8.57$ miles = 38,334

4.5 TRUCK VMT FOR TRANSPORTING MEAT BYPRODUCTS

The meat byproducts produced at each of the four processing facilities constitutes about 40% of the total live weight of the finished cattle. Based on previous research results, about 50% of the byproducts produced are transported by rail and the rest by truck (Bai et al. 2007). Some of the byproducts are exported to Mexico via Dallas and East Asia via Phoenix and Los Angeles. Small amounts of the byproducts such as technical (inedible) tallow and meat and bone meal are sent by trucks to local feed yards to feed swine, chickens, and turkeys. Because the quantities of byproducts sent to the feed yards are very small, previous researchers ignored the truck VMT for transporting these byproducts.

In this research, Dallas, Los Angeles, and Phoenix were considered the only destinations for transporting beef byproducts from the southwest Kansas region. The travel paths on the major highways were determined using TransCAD software, as shown in Appendix V. In Section 4.4, the annual number of finished cattle shipped to the Tyson Fresh Meats plant is calculated as 1,565,083. Each finished cattle produces about 480 lbs. (40%) of byproducts. Therefore, the annual quantity of byproducts produced at Tyson is 751,239,840 (1,565,083 x 480) pounds.

Since 50% of byproducts are distributed by truck and the capacity of a truck is 42,000 lbs, the annual number of truckloads for transporting byproducts from Tyson can be calculated as follows:

Annual truckloads for transporting byproducts from Tyson

= (50% x Annual quantity of byproducts at Tyson) / Truck capacity

= (50% x 751,239,840) / 42,000 lbs

= 8,943 truckloads

Previous researchers suggested that it was reasonable to assume that 65% of the byproducts transported by trucks were distributed south to Mexico via Dallas and the rest (35%) were distributed to East Asia via Los Angeles and Phoenix with a half-and-half split (Bai et al. 2007). As discussed in Section 4.3.4, only the trips from Tyson to Dallas have impact on the studied highway section. The annual number of truckloads from Tyson to Mexico via Dallas is 5,813 (8,943 x 65%). Thus, the annual truck VMTs on the studied pavement segments for transporting byproducts from Tyson Plant to Dallas can be estimated as:

Annual Truck VMT on PS 1 = $5{,}813 \times 10.13$ miles = 58,886

Annual Truck VMT on PS 2 = $5{,}813 \times 18.14$ miles = 105,448

Annual Truck VMT on PS 3 = $5{,}813 \times 4.29$ miles = 24,938

Annual Truck VMT on PS 4 = $5{,}813 \times 8.57$ miles = 49,817

4.6 SUMMARY

This chapter discussed the procedure and presented the results of annual truck VMTs on the studied pavement segments generated by the processed beef and related industries in the southwest Kansas. Based on the sequence of industries, the process of estimating truck VMT was broken down into five steps including:

- Truck VMT for transporting feeder cattle to feed yards in southwest Kansas;
- Truck VMT for transporting feed grain to feed yards in southwest Kansas;

- Truck VMT for transporting finished cattle to meat processing facilities in southwest Kansas;
- Truck VMT for transporting boxed beef to U.S. customers;
- Truck VMT for transporting meat byproducts.

The total annual VMT generated by the beef and related industries in southwest Kansas on the four pavement segments between Garden City, KS and Dodge City, KS, are summarized in Table 4.12.

The numbers listed in Table 4.12 represent one-way trips. After unloading the goods at destinations, trucks come back to their origins (roundtrip) with or without return shipment. According to findings of previous research, most of the trucks come back to their origins carrying goods such as tires, bagged fertilizer, groceries, and bagged animal feed to minimize the shipping costs (Bai et al. 2007). However, the percentage of the trucks with backhaul is not precisely known. Because of the limited information, this study assumes that the return trucks (to their origins) cause the same damage on the pavements as they did when shipping goods to their destinations. Thus, the VMT listed in Table 4.12 needs to be doubled to account for return trips. Table 4.13 shows the total daily & annual truck VMT of roundtrip shipments on the studied pavement segments in the southwest Kansas.

Table 4.12 Total Annual Truck VMT on the Studied Pavement Segments in Southwest Kansas (One-Way)

Pave. Seg. (PS)	Shipment	Annual Truckloads	Total Annual Truckloads	Annual Truck VMT	Total Annual Truck VMT
PS 1	Feed Cattle to Feed Yards	4,209	55,539	42,637	562,610
	Finished Cattle to Meat Processing Facilities	41,044		415,776	
	Boxed Beef to U.S. Customers	4,473		45,312	
	Byproducts to Export Destinations	5,813		58,886	
PS 2	Feed Cattle to Feed Yards	4,209	55,539	76,351	1,007,477
	Finished Cattle to Meat Processing Facilities	41,044		744,538	
	Boxed Beef to U.S. Customers	4,473		81,140	
	Byproducts to Export Destinations	5,813		105,448	
PS 3	Feed Cattle to Feed Yards	5,748	56,477	24,659	242,282
	Finished Cattle to Meat Processing Facilities	40,443		173,500	
	Boxed Beef to U.S. Customers	4,473		19,189	
	Byproducts to Export Destinations	5,813		24,938	
PS 4	Feed Cattle to Feed Yards	5,748	56,477	49,259	484,006
	Finished Cattle to Meat Processing Facilities	40,443		346,596	
	Boxed Beef to U.S. Customers	4,473		38,334	
	Byproducts to Export Destinations	5,813		49,817	

Table 4.13 Total Daily & Annual Truck VMT on the Studied Highway Segments in Southwest Kansas (Round-Trip)

Pavement Segment (PS)	Total Annual Truckloads	Total Daily Truckloads	Total Annual Truck VMT	Total Daily Truck VMT
PS 1	111,078	304	1,125,220	3,083
PS 2	111,078	304	2,014,954	5,520
PS 3	112,954	309	484,564	1,328
PS 4	112,954	309	968,012	2,652

Chapter 5

HIGHWAY DAMAGE COSTS ATTRIBUTED TO TRUCK TRAFFIC FOR PROCESSED BEEF AND RELATED INDUSTRIES

5.1 COST ESTIMATION METHODOLOGY

5.1.1 Background

The primary objective of this research was to estimate the highway damage costs due to the truck (e.g., tractor-trailers) traffic associated with the processed meat (beef) and related industries in southwest Kansas. The key to achieving this objective would be the understanding of how truck traffic would affect pavement performance and service life. Based on the literature review, various types of pavement performance prediction models have been developed not only to design new pavements, but also to evaluate in-service pavements, which in most cases were incorporated into a PMS system. As discussed in Chapter 2, a few models, such as Bayesian models, Probabilistic models, Empirical models, Mechanistic-Empirical models, and Mechanized models, have been developed. Among them, empirical models have been widely used in pavement damage studies because of their maturity and reasonable accuracy.

After a careful comparison, the cost estimation procedure used by Tolliver and HDR Engineering, Inc., was employed in this study for the pavement damage cost estimation with necessary modifications. The Tolliver's procedure utilized empirical models that relate the physical lives of pavements to truck-axle loads (Tolliver 2000). These models were originally developed from American Association of State Highway Officials (AASHO) road test data and later incorporated into the pavement design procedure developed by AASHTO and followed by many state DOTs including KDOT. In addition, the equations and functions used in these models have also been embedded in the pavement deterioration model of Highway Economic Requirements System (HERS), a comprehensive highway performance model used by the FHWA to develop testimony for Congress on the status of the nation's highways and bridges. A detailed technical documentation of HERS is presented in a report named "Highway Economic Requirements System - State Version" (2002). The data required for the analysis procedure were available in the KDOT PMIS database.

5.1.2 Relevant Pavement Damage Models and Equations

Two types of deterioration models were utilized in this study: a time-decay model and an equivalent single axle load (ESAL) or pavement damage model. The former took into account the pavement cost caused by environmental factors, and the latter analyzed the pavement damage due to truck traffic. The loss of pavement serviceability attributed to the environmental factors was estimated first and the rest of the serviceability loss was then assigned to truck axle loads. Equations deployed in the data analyses are described as follows.

5.1.2.1. <u>Traffic-Related Pavement Damage Functions</u>

Formulas for ESAL Factor

The deterioration of pavements was analyzed with a damage function that related the decline of pavement serviceability to traffic or axle passes. The general form of a damage function is illustrated as follows:

$$g = \left(\frac{N}{\tau}\right)^{\beta} \tag{5-1}$$

Where: g = an index of damage or deterioration;

N = the number of passes of an axle group of specified weight and configuration (e.g., a single 18-kip axle);

τ = the number of axle passes at which the pavement reaches failure (e.g., the theoretical life of the pavement);

β = deterioration rate for a given axle;

At any time between the construction (or replacement) and the pavement failure, the value of g will range between 0.0 and 1.0. When N equals zero for a newly constructed or rehabilitated section, g equals zero. However, when N equals the life of a highway section (τ), g equals 1.0.

One way to measure accumulated pavement damage is through a serviceability rating. If the ratio of decline in pavement serviceability relative to the maximum tolerable decline in serviceability is used to represent the damage index, then Equation (5-1) can be rewritten as follows:

$$\frac{P_I - P}{P_I - P_T} = \left(\frac{N}{\tau}\right)^{\beta} \tag{5-2}$$

Where: P_I = initial pavement serviceability rating;

P_T = terminal pavement serviceability rating;

P = current pavement serviceability rating.

ESAL Factors for Flexible Pavement. For flexible pavements, the unknown parameters (β and τ) in Equation (5-2) can be estimated through regression equations (Equation 5-3 and 5-4) developed based on AASHTO road test data.

$$\log_{10}(\tau) = 5.93 + 9.36\log_{10}(SN+1) - 4.79\log_{10}(L_1 + L_2) + 4.33\log_{10}(L_2) \tag{5-3}$$

$$\beta = 0.4 + \frac{0.081(L_1 + L_2)^{3.23}}{(SN+1)^{5.19} L_2^{3.23}} \tag{5-4}$$

Where: L_1 = axle load in thousand-pounds or kips;

L_2 = axle type (1 for single, 2 for a tandem, and 3 for triple axles);

SN = structural number of flexible pavement section.

Substituting 18 for L_1 and 1 for L_2 in Equation (5-3) yields Equation (5-5) which is the theoretical life of a flexible pavement for the reference axle (the single 18-kip axle) loads, or τ in (5-1) or (5-2).

$$\log_{10}(\tau) = 9.36\log_{10}(SN+1) - 0.2 \tag{5-5}$$

Substituting 18 for L_1 and 1 for L_2 in Equation (5-4) yields the rate of flexible pavement deterioration for the reference axle (the single 18-kip axle), as shown in Equation (5-6).

$$\beta_{18} = 0.4 + \frac{1094}{(SN+1)^{5.19}} \tag{5-6}$$

Where: β_{18} = deterioration rate for a single 18-kip axle load;

Substituting Equation (5-3) for τ, Equation (5-5) for N, Equation (5-6) for β in Equation (5-2) gives a damage factor for an 18-kip axle load. Alternatively, specifying L_1 and L_2 in Equation (5-4), and substituting Equation (5-4) for β in Equation (5-2), gives a damage factor for an axle type and load. The solutions of these equations yield two formulas for computing the equivalent rate of flexible pavement deterioration caused by a single-axle in comparison to an 18-kip axle load, which is the Equation (5-7), and by a tandem-axle group, which is the Equation (5-8).

$$\log_{10}(ESAL) = 4.79\log_{10}\left(\frac{L_1+1}{18+1}\right) + \frac{G}{\beta_{18}} - \frac{G}{\beta} \tag{5-7}$$

$$\log_{10}(ESAL) = 4.79\log_{10}\left(\frac{L_2+2}{18+1}\right) - 4.33\log_{10}(2) + \frac{G}{\beta_{18}} - \frac{G}{\beta} \tag{5-8}$$

In both formulas, G is computed as:

$$G = \log_{10}\left(\frac{P_I - P_T}{P_I - 1.5}\right) \tag{5-9}$$

Since the solutions of Equation (5-7) and (5-8) result in logarithms, the actual ESAL factor n is computed by taking the inverse logarithm of the appropriate expression, as shown in Equation (5-10).

$$n = 10^{\log_{10}(ESAL)} \tag{5-10}$$

Where: n = ESAL factor.

<u>ESAL Factors for Rigid Pavement.</u> From AASHTO road test data, the rate of rigid pavement deterioration caused by a single 18-kip axle is given by Equation (5-11).

$$\beta_{18} = 1 + \frac{3.63(19)^{5.2}}{(d+1)^{8.46}} \tag{5-11}$$

Where: d = pavement thickness in inches.

The rate of deterioration for all other axle loads on rigid pavement can be expressed as:

$$\beta = 1 + \frac{3.63(L_1 + L_2)^{5.2}}{(d+1)^{8.46} L_2^{3.52}} \tag{5-12}$$

A formula for computing the equivalent rate of rigid pavement deterioration caused by a given single-axle group is obtained by combining and simplifying previous equations. Equation (5-13) is used to convert rates of deterioration to rigid ESAL for single axle loads and Equation (5-14) is utilized to compute the equivalent rate of rigid pavement deterioration caused by a given tandem-axle group. G is computed using Equation (5-15) and ESAL factor n is computed using Equation (5-16).

$$\log_{10}(ESAL) = 4.62\log_{10}\left(\frac{L_1+1}{18+1}\right) + \frac{G}{\beta_{18}} - \frac{G}{\beta} \tag{5-13}$$

$$\log_{10}(ESAL) = 4.62\log_{10}\left(\frac{L_2+2}{18+1}\right) - 3.28\log_{10}(2) + \frac{G}{\beta_{18}} - \frac{G}{\beta} \tag{5-14}$$

$$G = \log_{10}\left(\frac{P_I - P_T}{P_I - 1.5}\right) \tag{5-15}$$

$$n = 10^{\log_{10}(ESAL)} \tag{5-16}$$

ESAL Life Functions

The ESAL life of a pavement is the cumulative number of equivalent single axle loads that the pavement can accommodate before it is rehabilitated. The ESAL life equations used in HERS are described in this section and they are derived from the same equations used to construct axle load equivalency formulas.

<u>ESAL Life Formulas for Flexible Pavements</u>. For the purpose of simplification, the lengthy function LGE shown in Equation (5-17) includes three variables XA, XB, and XG, which can be calculated using Equations (5-18) – (5-21).

$$LGE = XA + \frac{XG}{XB} \tag{5-17}$$

$$SNA = SN + \sqrt{\frac{6}{SN}} \tag{5-18}$$

$$XB = 0.4 + \left(\frac{1{,}094}{SNA}\right)^{5.19} \tag{5-19}$$

$$XG = \log_{10}\left(\frac{P_I - P_T}{3.5}\right) \tag{5-20}$$

$$XA = 9.36\log_{10}(SNA) - 0.2 \tag{5-21}$$

Where: LGE = cumulative ESALs that a pavement section can accommodate before reaching its terminal serviceability rating (in logarithmic form);

XB = rate at which a pavement's life is consumed with the accumulation of ESALs;

XG = pavement serviceability loss in terms of the maximum tolerable pavement PSR loss (from P_I to P_T);

XA = theoretical life of newly constructed pavement in ESALs;

SN = structural number of flexible pavement;

SNA = converted pavement structural number.

Finally, the actual lifecycle of a flexible pavement is computed by taking the inverse logarithm of LGE:

$$ESALlifecycle = 10^{LGE} \tag{5-22}$$

Equation (5-22) shows that the theoretical life of a pavement is directly related to pavement strength or structural number. However, the rate of pavement decay is inversely related to strength, as shown in Equation (5-19). Intuitively, both relationships make sense. In reality, pavements are frequently restored or rehabilitated before their PSR values decline to the terminal values. Consequently, their theoretical lives are rarely realized. In such instances, the solution of *XG* is negative and the ratio *XG/XB* adjusts the predicted ESAL life downward from its theoretical maximum. For example, the predicted ESAL life of a flexible pavement with an *SN* of 5.3 is approximately 21 million when the PSR is allowed to decline from 5.0 to 1.5, but only 10.4 million when the terminal PSR is 2.5.

ESAL Life Formulas for Rigid Pavements. The theoretical life of a rigid pavement is a function of the thickness of the concrete slab (d).

$$XA = 7.35 \log_{10}(d+1)0.06 \tag{5-23}$$

$$XB = 1 + \frac{16{,}240{,}000}{(d+1)^{8.46}} \tag{5-24}$$

$$XG = \log_{10} \frac{(P_I - P_T)}{3.5} \tag{5-25}$$

$$LGE = XA + \frac{XG}{XB} \tag{5-26}$$

$$ESALlifecycle = 10^{LGE} \tag{5-27}$$

5.1.2.2 Time-Related Deterioration of Pavements

A pavement will deteriorate over time due to environmental factors in the absence of truck traffic. Thermal cracking, differential heaving due to swelling subgrade or frost penetration, disintegration of surface materials due to freeze-thaw cycles, and other climatic/aging effects on materials are largely a function of the environment, and will result in a loss of pavement serviceability. Figure 5.1 depicts a likely form for the function (negative exponential). The negative exponential function suggests that pavement condition declines rapidly when initially exposed to the environmental elements, but then deteriorates at a decreasing rate over time. This type of decay process is similar to other natural and man-made phenomena, not just highways.

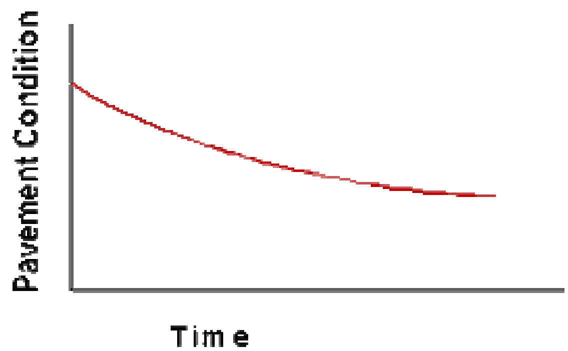


Figure 5.1 Theoretical Relationship Between Loss of Pavement Serviceability and Time (Tolliver 2000)

Assuming this theoretical relationship holds true, the decay rate due to environmental conditions can be found using the following equation:

$$\delta = \frac{-\ln\left(\frac{P_T}{P_I}\right)}{L} \tag{5-28}$$

Where: δ = Decay rate due to environmental losses;

P_T = Terminal PSR;

P_I = Initial PSR;

L = Maximum feasible life of pavement section.

From the decay rate, the PSR due to the environmental impact can be computed as:

$$P_E = P_I \times e^{(-t\delta)} \tag{5-29}$$

Where: P_E = PSR due to the environment impact;

t = Typical pavement performance period.

5.1.2.3 Calculation of Structural Numbers

For flexible pavements, the structural number can be determined using Equation (4-30).

$$SN = a_1 d_1 + a_1^* d_1^* + a_2 d_2 + a_3 d_3 \tag{5-30}$$

Where: d_1 = Thickness of surface layer (inches);

a_1 = Surface layer coefficient;

d_1^* = Thickness of old surface layer as a base course (inches);

a_1^* = Layer coefficient of old surface layer;

d_2 = Thickness of base (inches);

a_2 = Base layer coefficient;

d_3 = Thickness of subbase (inches);

a_3 = Subbase layer coefficient.

In this study, the data of pavement structure and depth of each pavement layer were collected from KDOT's Pavement Management Information System (PMIS). The layer coefficients shown in the Table 5.1 were used to compute structural numbers, as shown in Equation (5-30).

Table 5.1 Layer Coefficients Used to Compute Pavement Structural Numbers (Tolliver 2000)

Material	Layer Description	Layer Coefficient
Asphalt Concrete	New Top Surface Course	0.44
Asphalt Concrete	Worn Top Surface Course	0.37
Asphalt Concrete	Undisturbed Base	0.26
Bituminous Surface Treatment	Surface Course	0.24
Crushed Stone	Surface Course	0.15
Crushed Stone	Base Course	0.14
Portland Concrete Cement	Old Base	0.22
Cement Treated Base	Base	0.18
Gravel	Subbase	0.11

For composite pavements (AC overlay of PCC slab), the structural number for a composite pavement, particularly for Asphalt Concrete (AC) overlay of Portland Concrete Cement (PCC) slab, can be calculated by the following equation (5-31).

$$SN = SN_{ol} + SN_{eff} = \sum a_{oli} d_{oli} + a_{eff} D_{eff} m_{eff} \quad (5\text{-}31)$$

Where: SN_{ol} = Overlay structural number;

SN_{eff} = Effective structural number of the existing slab pavement;

d_{oli} = Thickness of surface and base layer of overlay (inches);

a_{oli} = Surface and base layer coefficient of overlay;

D_{eff} = Thickness of fractured PCC slab layer (inches);

a_{eff} = Corresponding structural layer coefficient (PCC slab);

m_{eff} = Drainage coefficients for fractured PCC slab

Table 5.2 shows the suggested layer coefficients for fractured slab pavements. For guidance in determining the drainage coefficients, due to lack of information on drainage characteristics of fractured PCC, a default value of 1.0 for m_{eff} is recommended.

Table 5.2 Suggested Layer Coefficients for Fractured Slab Pavements (AASHTO 1993)

Material	**Slab Condition**	**Layer Coefficient**
Break/Seal JRCP	Pieces greater than one foot with ruptured reinforcement or steel/concrete bond broken	0.20 to 0.35
Crack/Seal JPCP	Pieces one to three feet	0.20 to 0.35
Rubblized PCC (any pavement type)	Completely fractured slab with pieces less than one foot	0.14 to 0.30
Base/subbase granular and stabilized	No evidence of degradation or intrusion of fines Some evidence of degradation or intrusion of fines	0.10 to 0.14 0.0 to 0.10
JRCP: Jointed Reinforcement Concrete Pavements JPCP: Jointed Plain Concrete Pavements		

5.1.3 Pavement Damage Cost Analysis Procedure

Figure 5.2 presents the flowchart for the pavement damage cost analysis procedure. The steps involved in the analysis of this research are:

1. The various stages in the movement of cattle and grain in southwest Kansas area were examined and the origins and destinations were identified for each stage of the movements. Truckload data associated with processed beef and related industries was then collected.
2. The highway section under study, US 50/400 between Dodge City and Garden City, was broken into segments according to pavement characteristics with

beginning and ending milepost references. Key highway attributes of each pavement segment were compiled using KDOT's PMIS database, including the functional class, pavement type, structural number or slab thickness, and design (initial) and terminal PSR. The truck traffic was estimated and assigned in the southwest Kansas area using TransCAD software. Based on the identified truck routes and the collected truckload data, the total truck VMTs associated with processed beef and related industries on each pavement segment were estimated.

3. ESAL factors were computed for the truck type 3-S2 traveling on each highway segment.
4. Truck ESAL factors were multiplied by the truck VMTs associated with the processed beef and related industries to compute annual ESALs for each pavement segment.
5. The lives of the studied pavement segments in terms of ESALs were determined. In this step, the ESAL life functions were used to compute the ESAL lives of studied pavements. The ESAL life is the cumulative number of axle passes that will cause the PSR of a pavement section to decline from its design level to its terminal serviceability rating irrespective of the time involved.
6. The maximum life of a pavement segment was defined in terms of a tolerable decline in PSR. For the studied highway, KDOT designs for an initial PSR at 4.2 and a terminal PSR at 2.5. Thus, the maximum tolerable decline in PSR is

1.7. In this research, the maximum feasible life of a pavement segment was determined as 30 years according to KDOT pavement design criteria.

7. The loss in PSR from environmental factors was computed using the time-related deterioration function for a typical design performance period for the studied pavement segments. Only the remaining pavement rehabilitation costs were considered because of traffic.
8. Unit costs per ESAL were computed by multiplying the average resurfacing or reconstruction costs per mile by the percent of PSR loss due to traffic and dividing by the ESAL lives of the pavement segments. To illustrate the process, assume that a pavement segment has an ESAL life of 500,000, rehabilitation and reconstruction cost of \$300,000 per mile, and 40% of the pavement deterioration is due to environmental factors. In this example, the rehabilitation cost due to traffic is \$300,000 x (1-40%)/500,000 = \$0.36 per ESAL.
9. The contributed pavement damage cost for the studied highway section was computed by multiplying the annual ESALs associated with processed beef and related industries by the average unit cost per ESAL.

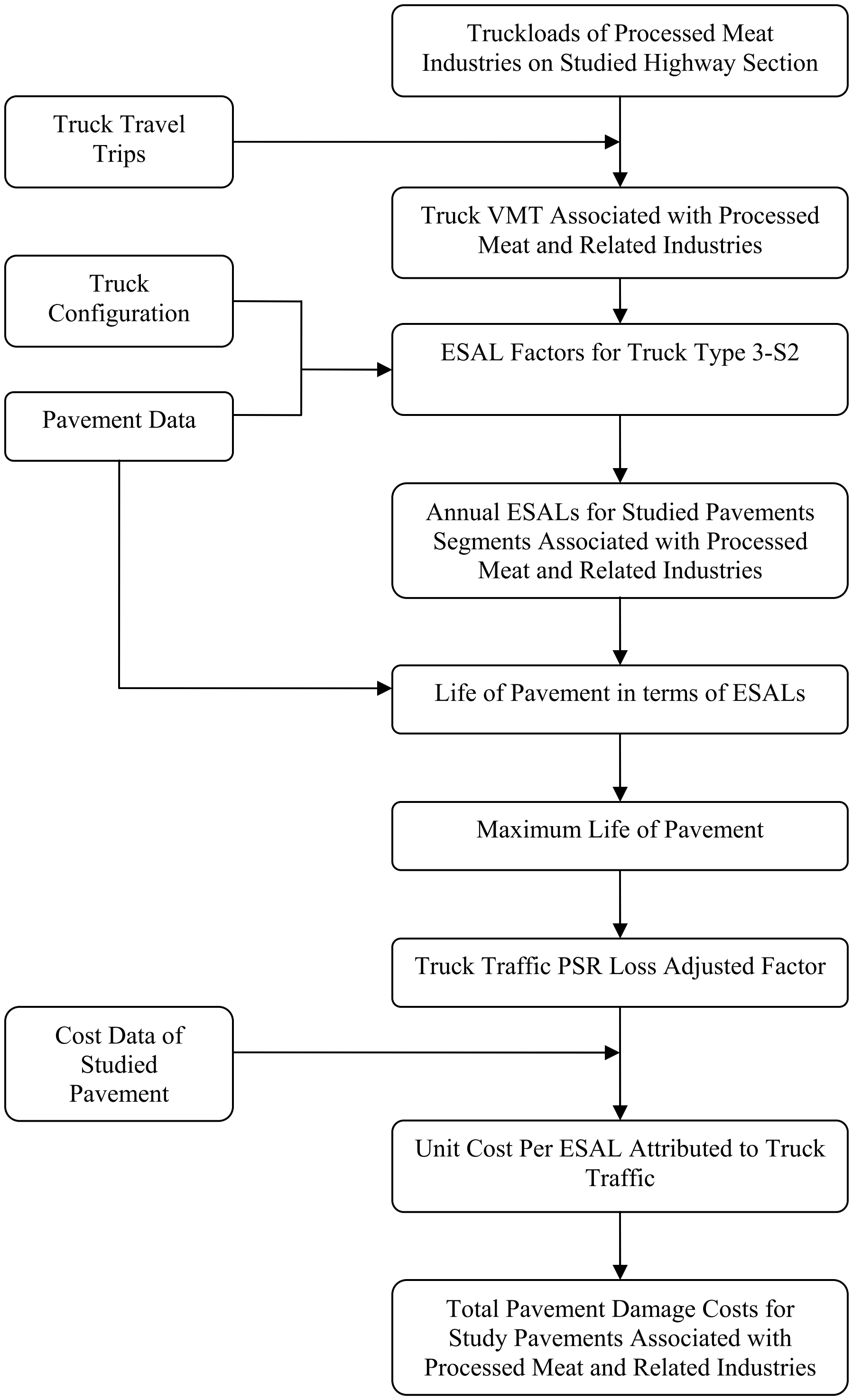


Figure 5.2 Flowchart of Pavement Damage Cost Analysis Procedure

5.2 DATA INPUT REQUIREMENTS

The key data required by the calculations included the configuration of trucks and the pavement information of the highway section under study. As discussed in Section 3.2.1, it was assumed that all grain hauling vehicles were type 3-S2 with five-axle semi-tractor trailer configurations, and loading configurations were assumed to be 10/35/35. The detailed configurations of this vehicle type can be found in the Comprehensive Truck Size and Weight Study prepared for the U.S. Department of Transportation (USDOT 2000).

The important pavement data inputs required for this study included:

- Structural number for flexible pavement (SN)
- Initial PSR (p_0)
- Terminal PSR (p_t)
- Maximum feasible life of pavement segment in years (L)
- Typical pavement performance (τ)

KDOT maintains all the pavement segment data in its PMIS database. In this research, the required pavement data for the calculations were provided by KDOT.

5.3 PAVEMENT DAMAGE COST ANALYSIS

The annual pavement damage costs attributed to these VMTs were evaluated based on the estimated annul total truck VMTs on the studied pavement segments.

The characteristics of the pavement segments were obtained from the KDOT PMIS database:

- Designation as U.S., State, or Interstate highway
- Route number
- Beginning and ending points of highway segments
- Pavement type
- Length of pavement segment
- Pavement structure number
- Maintenance activity and cost record

To calculate the pavement damage costs due to trucks for processed beef and related industries, it was necessary to calculate ESAL factors for the typical truck type and pavements. In this study, the selected truck model was a 3-S2 tractor-and-trailer with a loading configuration of 10/35/35. This configuration means that the tractor unit applies a 10,000 pound load to the front axle, and each of two tandem axle groups under the trailer supports 35,000 pounds. The maximum legal GVW of the truck is 80,000 pounds.

The impact of this truck on pavement varies depend on pavement characteristics. There are three basic steps involved in calculating the ESAL factor. First, the rate of deterioration was computed for the 18,000-pound reference axle. Second, the deterioration rates of the interest axle loads were computed. Finally, the two deterioration rates were used to compute the ESAL factors. These computations required the knowledge of the type of axle group, the load in kips, the initial and terminal PSR, pavement characteristics and type. As mentioned earlier, the four pavement segments on the studied highway section (US 50/400 between Garden City and Dodge City) were considered as flexible pavements during the calculation of pavement damage, except for the calculation of the structural numbers where equations for composite pavements were available. The following sections describe the pavement damage computation procedure and corresponding results.

5.3.1 Calculation of ESAL Factors and Annual ESALs

Pavement structural numbers are key inputs for the calculation of ESAL factors. The numbers for pavement segments 1 and 2 were obtained directly from KDOT PMIS system as 5.4 and 3.05. On the other hand, the structure numbers for segments 3 and 4 had to be computed based on their pavement structure information. As described in Chapter 3, pavement segment 3 had the surface layer of 40 mm (1.57 in) BM-1T and the base course was the original layers with a total thickness of 330 mm (13.0 in). In Kansas, KDOT designs full depth asphalt pavements without a base layer. The subbase layer is the subgrade (natural soil). Equation (5-30) was used to determine the SN for PS 3. The layer coefficients a_1 and a_1^* were selected from Table 5.1 as 0.4 and 0.26, respectively. Therefore, the SN for segment 3 was calculated as follows:

SN (PS 3) = $1.57 \times 0.4 + 13.0 \times 0.26 = 4.0$

PS 4 is a composite pavement segment which has a surface layer of 38 mm (1.5 in) BM-1T, a 151 mm (5.95 in) base course of HMA (Hot Mix Asphalt), and a 178 mm (7.01 in) subbase layer of Concrete Pavement on the subgrade (natural soil).

Based on Table 5.2, the layer coefficients a_{o1}, a_{01}^{*} and a_{eff} were selected as 0.4, 0.26 and 0.22, respectively. Equation (5-31) was used to compute SN for PS 4:

SN (PS 4) = $(1.5 \times 0.4 + 5.95 \times 0.26) + 7.01 \times 0.22 = 3.69$

With the structural numbers known, the front-axle ESAL was calculated using Equations (5-4), (5-6), (5-7), (5-9), and (5-10) described in Section 5.1.2. For the 3-S2 trucks used in this study, the load applied to this axle was 10 kips. The initial and terminal PSR values were 4.2 and 2.5, as used by KDOT for pavement management. A rear tandem axle ESAL factor for the 3-S2 truck was computed in the same manner as for the single axle ESAL, with a different load of 35 kips and using Equations (5-4), (5-6), (5-8), (5-9), and (5-10). The total ESAL factor value n for a standard truck was the sum of the front single axle and two rear tandem axle groups. Then, the truck ESAL factor was multiplied by the annual truck VMTs to compute the annual ESALs for each pavement segment. The results are presented in Table 5.3.

Table 5.3 Calculation of ESAL Factors and Annual ESALs

Pave. Seg. No.	SN	P_I	P_T	L_1	L_2	β_{18}	β (β_{10}, β_{35})	$\log_{10}^{(ESAL)}$	G	n	$\sum n$	VMT	Annual ESALs
1	5.4	4.2	2.5	10	1	0.472	0.412	-1.076	-0.201	0.084	1.310	1,125,220	1,473,852
				35	2		0.466	0.088		1.226			
2	3.05	4.2	2.5	10	1	1.170	0.532	-0.931	-0.201	0.117	1.356	2,014,954	2,731,841
				35	2		1.106	0.093		1.239			
3	4.0	4.2	2.5	10	1	0.658	0.444	-0.990	-0.201	0.102	1.342	484,564	650,209
				35	2			0.093		1.240			
4	3.69	4.2	2.5	10	1	0.759	0.461	-0.966	-0.201	0.108	1.349	968,012	1,306,016
				35	2		0.730	0.094		1.241			

SN: Structural number of Pavement
P_I: Initial PSR
P_T: Terminal PSR
L_1: Axle load in thousand-pounds
L_2: Axle type
β_{18}: Deterioration rate for a single 18-kip axle load, calculated using Equation (5-6)
β: Deterioration rate for a given axle load, calculated using Equation (5-4)
$\log_{10}^{(ESAL)}$: calculated using Equation (5-7) and (5-8)
G: calculated using Equation (5-9)
n: ESAL factor, computed using Equation (5-10)

5.3.2 Determination of the Pavement ESAL Lives

The maximum life of a pavement was defined in terms of tolerable decline in PSR. The studied highway segments were designed by KDOT at an initial PSR of 4.2 and a terminal PSR of 2.5: a maximum tolerable decline in PSR was 1.7. The life of the studied pavement segments in terms of traffic, or ESAL life, was determined using this maximum tolerable PSR decline. ESAL life is the total number of axle passes that would cause the pavement to decline to its terminal PSR irrespective of the time involved. The ESAL life of each studied pavement segment was determined using Equations (5-17), (5-18), (5-19), (5-20), (5-21) and (5-22) of the HERS procedure. The results are shown in Table 5.4.

5.3.3 Determination of the Per-Mile Pavement Maintenance Costs and Per-ESAL Unit Cost

Table 5.5 presents the actual rehabilitation, resurfacing, and reconstruction costs of four pavement segments that were provided by KDOT. It includes a brief description of each pavement segment, project numbers, action years, and total costs. Although the maintenance was performed in a specific year, the pavements actually decayed gradually. It was not reasonable to simply assume that the cost for each maintenance action was only for that year. For example, a cost of $999,522 spent in 1997 should be considered as the pavement damage of PS 2 between 1985 (when the last maintenance action took place) and 1997, rather than just for that year (1997).

Table 5.4 Calculation of Pavement ESAL Lives

Pave. Seg. No.	SN	P_I	P_T	SNA	XA	XB	XG	LGE	ESAL Life	L (years)	t (years)	δ	P_E
1	5.4	4.2	2.5	6.454	7.380	3.711E+11	-0.314	7.380	2.399E+07	30	14	0.008	3.78
2	3.05	4.2	2.5	4.453	5.871	2.548E+12	-0.314	5.871	7.430E+05	30	14	0.008	3.78
3	4.0	4.2	2.5	5.225	6.521	1.111E+12	-0.314	6.521	3.320E+06	30	14	0.008	3.78
4	3.69	4.2	2.5	4.965	6.314	1.447E+12	-0.314	6.314	2.060E+06	30	14	0.008	3.78

SN: Structural number of Pavement
P_I: Initial PSR
P_T: Terminal PSR
SNA: Converted pavement structural number, calculated using Equation (5-18)
XA: Theoretical life of newly constructed pavement in ESALs, calculated using Equation (5-21)
XB: Rate at which a pavement's life is consumed with the accumulation of ESALs, computed using Equation (5-19)
XG: Maximum tolerable pavement PSR loss, calculated using Equation (5-20)
LGE: Cumulative ESAL life in logarithmic form, calculated using Equation (5-17)
ESAL Life: calculated using Equation (5-22)
L: Maximum feasible life of pavement
t: Typical pavement performance period
δ : Decay rate due to environmental losses, computed using Equation (5-28)
P_E: PSR due to the environmental impact, computed using Equation (5-29)

Table 5.5 Maintenance Cost Data for Studied Pavement Segments

Pavement Segment		Cost Data		
No.	Descriptions	Year	Project	Total Cost
PS 1	US-50 Finney Co. East of Garden City to the ECL	2005	K-6374-01	$15,908,221
PS 2	US-50 Gary County from the WCL to Cimarron	1985	K-1764-01	$3,074,770
		1997	K-6190-01	$999,522
		2004	K-9324-01	$1,653,059
PS 3	US-50 in Gray Co. from Cimarron to the ECL	1992	K-4038-01	$1,685,548
		2001	K-8146-01	$746,771
PS 4	US-50 in Ford Co. from the WCL east to US-400	1981	K-1228-01	$3,595,654
		1989	K-3643-01	$272,433
		1992	K-4039-01	$627,261
		1992	K-4609-01	$448,390
		2001	K-8145-01	$220,173
		2003	K-8145-02	$1,730,826

In addition, the money spent in previous years has to be converted to the current value to reflect a per-ESAL cost that is more meaningful for the present time. The conversion was done through the following two steps.

Converting Maintenance Costs to Year 2007 Value

Based on economic theory, the spending ($M_{ti}^{S} current\$$) of a pavement maintenance activity in the activity year (*ti*) can be converted to the current 2007 dollar value (M_{ti}^{S}) given an interest rate (r) by Equation (5-32) (Sullivan 2003).

$$M_{ti}^{S} = M_{ti}^{S} current\$ \times (1+r)^{2007-ti} \tag{5-32}$$

Where: M_{ti}^{S} = year 2007 value;

$M_{ti}^{S} current\$$ = dollar spent for maintenance project;

S = pavement segment number; 1, 2, 3, 4;

ti = year of maintenance action; 1981, 1985, 1992, ……, 2005;

r = an interest rate.

The Producer Price Index (PPI) data from 1981 to 2006 were used to determine the interest rate. The PPI measures the average change over time in the selling prices received by domestic producers for their output. The prices included in the PPI are from the first commercial transaction for various products and services (USDL 2007). Figure 5.3 illustrates the PPI change in materials and components for construction from 1981 to 2007 and Figure 5.4 shows the PPI change in construction machinery and equipment during the same reference period. Appendix VI lists the detailed PPI data of these two types of commodities that are used for pavement maintenance. The average of the PPI change rate per year for construction materials and components is 2.68% and the average of the PPI change rate per year for construction machinery and equipment is 2.62%. In this research, 3% was used as the rounded average interest rate (*r*). Table 5.6 shows the maintenance costs of studied highway section in year 2007 dollars converted using Equation (5-32).

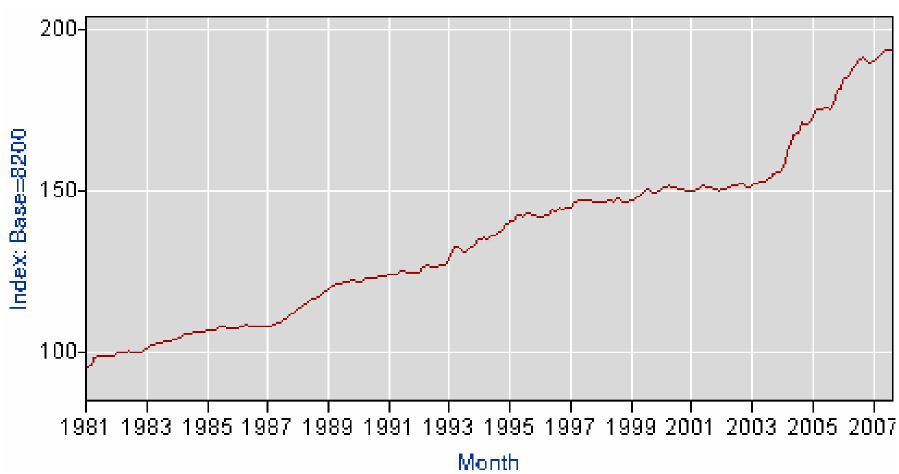


Figure 5.3 PPI Change in Materials and Components for Construction from 1981 to 2007 (USDL 2007)

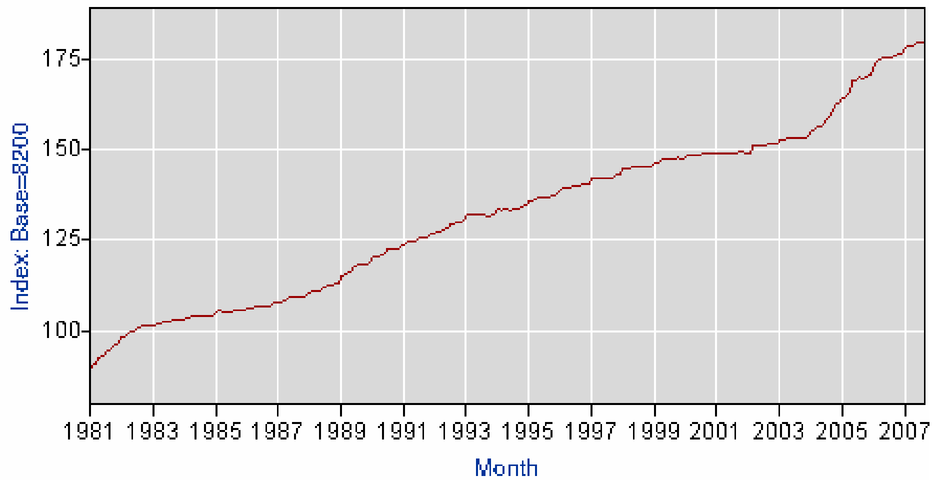


Figure 5.4 PPI Change in Construction Machinery and Equipment from 1981 to 2007 (USDL 2007)

Table 5.6 Maintenance Costs in Year 2007 U.S. Dollars

Pavement Segment		**Maintenance Costs**			
No.	**Descriptions**	**Year**	**Project**	**Previous Dollar**	***2007 Dollar**
PS 1	US-50 Finney Co. East of Garden City to the ECL (10.13 miles)	2005	K-6374-01	$15,908,221	$16,887,032
PS 2	US-50 Gary County from the WCL to Cimarron (18.14 miles)	1985	K-1764-01	$3,074,770	$5,891,577
		1997	K-6190-01	$999,522	$1,343,274
		2004	K-9324-01	$1,653,059	$1,806,342
PS 3	US-50 in Gray Co. from Cimarron to the ECL (4.29 miles)	1992	K-4038-01	$1,685,548	$2,626,029
		2001	K-8146-01	$746,771	$891,684
PS 4	US-50 in Ford Co. from the WCL east to US-400 (8.57 miles)	1981	K-1228-01	$3,595,654	$7,754,356
		1989	K-3643-01	$272,433	$463,799
		1992	K-4039-01	$627,261	$977,252
		1992	K-4609-01	$448,390	$698,577
		2001	K-8145-01	$220,173	$262,898
		2003	K-8145-02	$1,730,826	$1,948,060

*: Interest Rate r = 3%

Computing Average Annual Per-Mile Maintenance Costs

To compute average annual maintenance costs, it was necessary to determine the time period covered by each maintenance expenditure. In this study, the maintaining time period of each expenditure (M_{ti}^{S}) was considered as the interval in years (I_i) between two contiguous maintenance activities. Using the constant dollar smoothing method, annual maintenance spending (A_t^S) on a pavement segment was computed using Equation (5-33).

$$A_t^S = \frac{M_{ti}^S}{I_i} = \frac{\sum M_{ti}^S}{t_{i+1} - t_i} \tag{5-33}$$

Where: A_t^S = average annual maintenance cost in 2007 dollar for segment S at time $t \in [t_i, t_{i+1}]$;

I_i = interval years.

According to the KDOT pavement management policy, the maximum feasible life of a pavement is 30 years. From KDOT's latest Pavement Management System data (2007), the anticipated design life for full depth asphalt pavement was 14 years before a maintenance action was needed. The anticipated life was 6 years before an action was needed after a light rehabilitation with any overlay less than 1.5 inches or surface recycle actions. The performance period of the studied pavement segments, in terms of the number of years after a new pavement segment is resurfaced, was considered as 14 years because the data showed that none of the segments had any overlays less than 1.5 inches. Therefore, the average annual maintenance expenditure per mile for the studied pavement segments was calculated as follows.

Average annual per-mile maintenance expenditure for PS 1

$$= \frac{(\$16{,}887{,}032)/14\,years}{10.13\,miles} = \$119{,}003$$

Average annual per-mile maintenance expenditure for PS 2

$$= \frac{(\$5{,}891{,}577 + \$1{,}343{,}274 + \$1{,}806{,}343)/(2004 - 1985 + 14)\,years}{18.14\,miles} = \$15{,}103$$

Average annual per-mile maintenance expenditure for PS 3

$$= \frac{(\$2{,}626{,}029 + \$891{,}684)/(2001 - 1992 + 14)\,years}{4.29\,miles} = \$35{,}651$$

Average annual per-mile maintenance expenditure for PS 4

$$= \frac{(\$7{,}754{,}356 + \$463{,}799 + \$977{,}252 + \$698{,}577 + \$262{,}898 + \$1{,}948{,}060)/(2003 - 1981 + 14)\,years}{8.57\,miles}$$

$$= \$39{,}236$$

The annual per-mile maintenance expenditure for each of the segments calculated here was due to both environmental factors and truck traffic. Since the purpose of this study was to estimate the maintenance cost attributed to the truck traffic generated by the beef and related industries, the impact of environmental factors should be excluded. The PSR loss of each segment due to environmental factors for the design period of 14 years was determined using the time decay Equations (5-28) and (5-29). Given KDOT's policy for initial PSR of 4.2 and terminal PSR of 2.5, with a maximum feasible life of 30 years, the PSR due to the environmental factor (P_E) was computed as 3.78 (also shown in Table 5.4). The PSR declined by (4.2-2.5) - (4.2-3.78) = 1.28 during the design period of 14 years irrespective of truck traffic**.** Because the maximum tolerable loss in PSR is 1.7, then the percent of the pavement rehabilitation costs due to truck traffic was estimated as follows:

Percent of maintenance costs due to related truck traffic = 1.28/1.7 = 75%.

Thus, the average annual maintenance cost per mile of each pavement segment needs to be adjusted by a factor of 75% to isolate damage solely attributed to truck traffic. Table 5.7 shows the adjusted results of average annual maintenance costs in 2007 dollars for each segment.

Table 5.7 Average Annual Maintenance Costs per Mile Attributed to Truck Traffic

Pav. Seg. No.	Average Annual Maintenance Costs Per Mile	Adjusted Factor for Truck Traffic	Average Annual Per-Mile Maintenance Costs Attributed to Truck Traffic
PS 1	$119,003	0.75	$89,252
PS 2	$15,103	0.75	$11,328
PS 3	$35,651	0.75	$26,738
PS 4	$39,236	0.75	$29,427

Then, the unit cost per ESAL for each pavement segment was computed by dividing the average per-mile maintenance cost by the determined ESAL life of the same segment. The results are shown in Table 5.8, columns 3 and 5.

Table 5.8 Pavement Maintenance Costs Results

Pavement Segment		Average Annual Maintenance Costs in 2007 Dollar Per Mile	ESAL Life of Pavement	Maintenance Costs in 2007 Dollar per ESAL	Annual ESALs associated with Processed Meat related Industries	Pavement Damage Costs in 2007 Dollar attributable to Processed Meat Related Industries
No.	Descriptions					
PS 1	US-50 Finney Co. East of Garden City to the ECL (10.13 miles)	$89,252	23991498.19	$0.004	1,473,773	$5,483
PS 2	US-50 Gary County from the WCL to Cimarron (18.14 miles)	$11,328	743019.30	$0.015	2,014,846	$41,645
PS 3	US-50 in Gray Co. from Cimarron to the ECL (4.29 miles)	$26,738	3319626.53	$0.008	650,185	$5,237
PS 4	US-50 in Ford Co. from the WCL east to US-400 (8.57 miles)	$29,427	2060296.95	$0.014	1,305,946	$18,653
Total Pavement Damage Costs in 2007 Dollar						$71,019

5.3.4 Damage Costs Attributed to Beef and Related Industries

As mentioned in previous sections, the values of the parameters used in the pavement damage analysis for the four pavement segments and the calculation results are summarized in Tables 5.3 and 5.4. The damage cost for each of the studied pavement segments attributed to the truck traffic generated by the beef and related industries in the southwest Kansas was estimated as the unit cost per ESAL multiplied by the annual ESALs on each segment. The results are presented in the last column of Table 5.8. After summing costs from four pavement segments, the result represents the annual pavement damage costs on the studied highway section attributed to processed beef and related industries in southwest Kansas.

In summary, for the studied highway section, 41.13 miles on US 50/400 between Garden City and Dodge City, the total annual highway damage associated with processed meat and related industries in southwest Kansas was estimated at \$71,019, or \$1,727 per mile. The annual damage cost per truck per mile was approximately \$0.02. Table 5.9 lists the pavement length of major highways in the southwest Kansas region. If the same truck traffic were to be present on all these major highways in southwest Kansas (approximately 1835 miles), the total annual damage costs attributed to processed meat and related industries would be \$3,169,045.

The meat processing industry, especially for boxed beef and byproducts, is expected to grow 13% from 2007 to 2015 nationwide. For feed yards, the growth of feeder cattle will be proportional to the industry growth. Some researchers projected that the number of cattle could even triple by then. In addition, related industries, such as dairy, were projected to grow significantly. Overall, the truck volumes generated by the processed meat and related industries are projected to increase by 10% - 20% on highways in southwest Kansas region from 2007 to 2015 and may continue growing in the future (Bai et al. 2007). Assuming the industry's growth is equal for each year, Figure 5.5 shows the projected future annual pavement damage costs associated with meat processing and related industries on the studied highway section. Figure 5.6 shows the projected future annual pavement damage costs associated with the meat processing and related industries on the major highways in southwest Kansas, assuming the major highways carry the same truck traffic as that of the studied pavement section.

Table 5.9 Pavement Length of Major Highways in Southwest Kansas Region

Major Highways	Mileage in Southwest Kansas
US 83	123
US 183	159
US 283	119
US 50, 56 and 400	379
US 54	100
US 160	149
K 4	106
K 23	127
K 25	120
K 27	122
K 96	161
K 156	99
Others	71
Total	1835

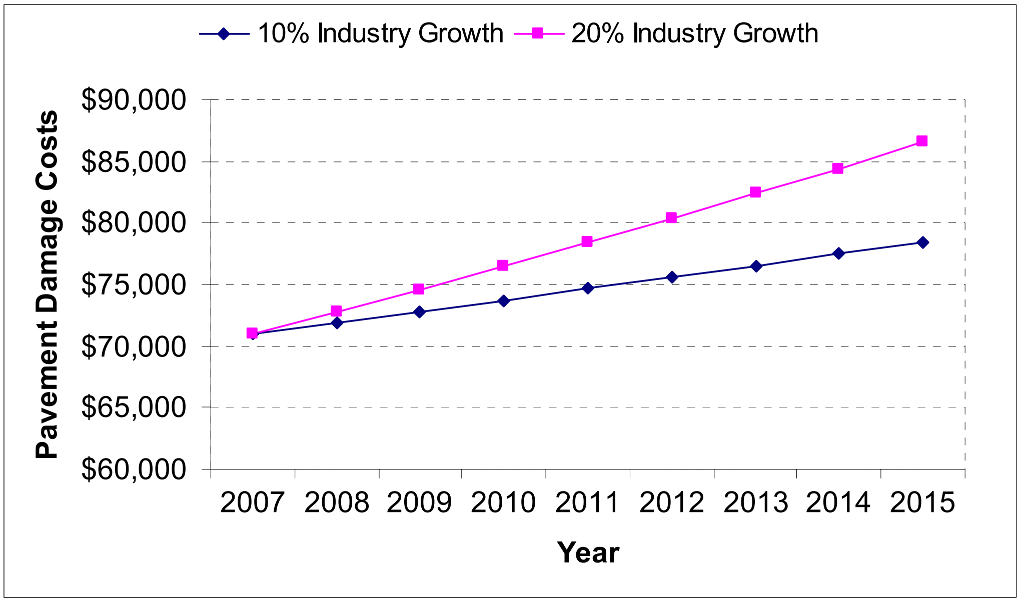


Figure 5.5 Projected Future Annual Pavement Damage Costs Associated with Meat Processed and Related Industries on the Studied Highway Section

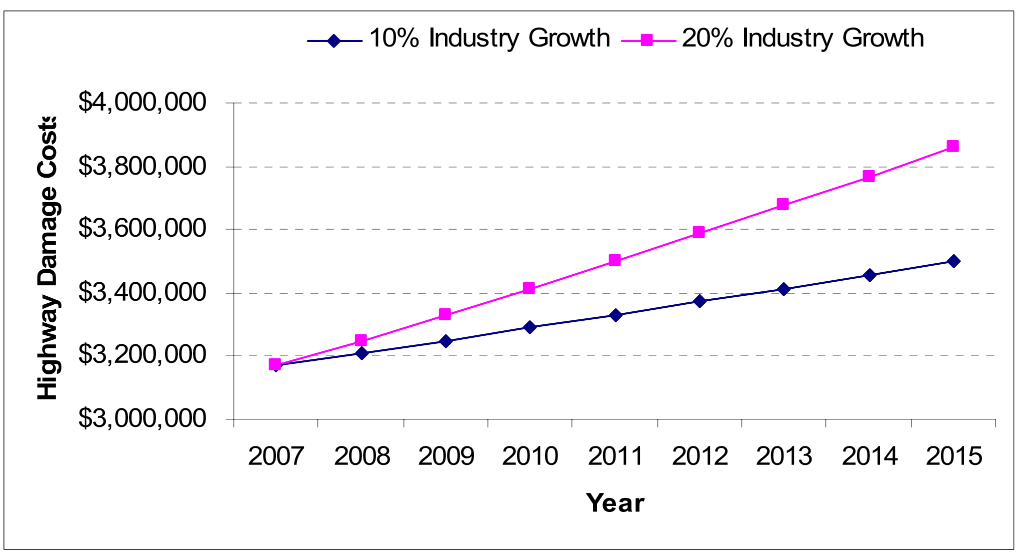


Figure 5.6 Projected Future Annual Pavement Damage Costs Associated with Meat Processed and Related Industries on the Major Highways in Southwest Kansas

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Kansas is one of the leaders in meat production in the United States. In the southwest Kansas region, there are more than three hundred feed yards and several of the biggest meat processing plants in the nation. Heavy trucks (e.g., tractor-trailers) have been used primarily for transporting processed meat, meat byproducts, grain, and other related products. With the continuous growth of these industries, there will be more trucks on highways transporting meat and meat-related products in southwest Kansas.

The high truck VMT generated by the beef processing and related industries in southwest Kansas causes noteworthy damage to Kansas highway pavements, which in turn leads to more frequent maintenance actions and ultimately more traffic delays and congestion. A systematical analysis of heavy-truck-related highway maintenance costs will be beneficial for the selection of cost-effective transportation modes for the meat processing and related industries in southwest Kansas. It also helps KDOT to assess highway maintenance needs and to set up maintenance priorities. Meanwhile, the analysis results will be valuable for the determination of reasonable user costs.

To thoroughly study the pavement damage caused by beef-industry-related truck traffic, the researcher first conducted a comprehensive literature review to obtain relevant background knowledge. Second, data for truckloads generated by the beef and related industries and the studied pavement data were determined. Third, based on these data, the total truck VMT and annual equivalent single axle loads (ESALs) associated with the industries for the studied pavement segments were calculated. Fourth, the unit cost per ESAL was computed and adjusted by the truck traffic PSR loss factor. Finally, the total damage costs associated with processed beef and related industries on the studied pavement segments were estimated by multiplying the unit cost per ESAL by the total annual ESALs generated by the industries.

In this study, the researcher used a systematic pavement damage estimation procedure that synthesized several existing methodologies including HERS and AASHTO methods. The procedure utilized in this research provides a practical approach to estimate pavement damage costs attributed to truck traffic associated with certain industries on specific pavement segments. Using this approach, general pavement damage costs associated with heavy trucks could also be estimated if the truck traffic volume and predominant truck types were known.

The study results showed that, for the 41-mile-long highway section, US 50/400 from Garden City to Dodge City, the total highway damage cost associated with processed meat related industries was estimated as $71,019 per year, or $1,727 per mile. The damage cost per truck per mile was approximately $0.02. If the same truck traffic was presented on all major highways in southwest Kansas (1835 miles), the total damage cost attributed to the processed meat and related industries would be $3,169,045 per year.

It was estimated that, every day, 309 trucks on the studied highway section were generated by the processed meat and related industries, about one third of the truck traffic on the traffic count map provided by KDOT. This number may be underestimated because of the following reasons. First, the researcher assumed that grain was shipped by train to elevators and then distributed by trucks only through local roads instead of major highways such as US 50/400. Second, the travel routes analyses were based on the major highway network in Kansas and used only shortest-path criterion that assumes all driver decisions are rational and are made with good information at the travel times. These assumptions may be biased and may result in underestimating the truck traffic volume.

The accuracy of the study results may be affected by some other factors. For example, it was noted during data collection that a certain proportion of the trucks were frequently overloaded to lower their shipping costs. However, because of the limited information, this study assumed that all trucks had the standard weight. Other assumptions such as shipping origin and destination locations, shipping proportional distributions, and truck route selections may also lead to a certain degree of estimation errors. To minimize these errors, more accurate and comprehensive data on the truck traffic and beef and related industries would be necessary.

6.2 RECOMMENDATIONS

Based on the study results, the researcher offers the following recommendations:

- In this study, the highway damage that was caused by the truck traffic generated by beef and related industries in southwest Kansas was assessed. The assessment helps traffic engineers and other stakeholders to understand the truck travel paths and highway pavement maintenance costs attributable to the beef industries in southwest Kansas. There is a need to estimate the highway damage caused by other vital regional industries so that the causal relations between the highway maintenance costs and these industries can be better understood. This knowledge would be useful for highway project prioritization and project funding allocations. The analysis results would be a good reference for determination of reasonable user costs for different industries.
- Meat processing and related industries have been predicted to continue growing in the future. Truck volumes for these industries were projected to increase from 10% to 20% on highways in the southwest Kansas region from

2007 to 2015. In addition, the growth of other related businesses in the study area, including dairy farms, milk processing plants, and ethanol plants, will contribute to the increase of truck traffic. The large amount of truck VMTs would cause rapid deterioration of Kansas highways, not to mention increasing the crash rate. Poor pavements constrain travel speeds and cause damages for all motor vehicles traveling on them. Poor pavements not only affect traveler safety and comfort, but increase vehicle-operating costs such as maintenance, and depreciation. To mitigate these impacts, using railroads as an alternative to truck transportation needs to be considered. The researcher recommends the study of the feasibility and economic benefits of increased use of rail transportation for beef and related industries. There is a need to study the rail infrastructure in southwest Kansas and to determine if it is feasible as an alternative transportation mode and how existing business could use it. Location studies are also needed to select the best places to establish new businesses (e.g., dairy and ethanol) to better utilize all transportation modes available in the southwest Kansas area.

- Because of data limitations, this study could not estimate the net costs of pavement damage caused by beef-related truck traffic. In a future study, highway revenues generated from fuel taxes and other user fees should be estimated and subtracted from highway maintenance costs to yield the net costs of highway pavement damage due to beef and related industries in southwest Kansas.

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APPENDICES

Appendix I: Shortest Paths from County Centroids to Feed Yards in the Respective County

Appendix II: Shortest Paths from Entry Points in the Boundary to County Centroids

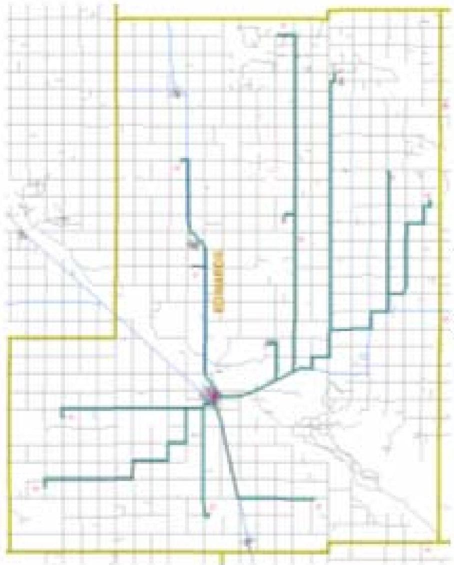
Appendix III: Shortest Paths from County Centroids to Four Meat Processing Plants in Southwest Kansas

Appendix IV: Shortest Paths from Entry Points to Four Meat Processing Plants in Southwest Kansas

Appendix V: Shortest Paths from Four Meat Processing Plants to U.S. Cities

Appendix VI: Producer Price Index Detailed Data (1981-2007) (USDL 2007)

APPENDIX I: SHORTEST PATHS FROM COUNTY CENTROIDS TO FEED YARDS IN THE RESPECTIVE COUNTY

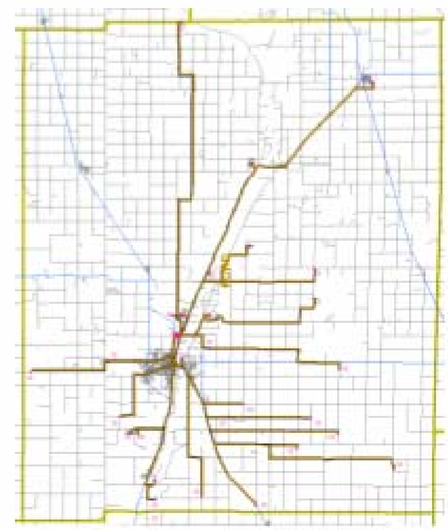


Edwards

Comanche

Clark

Grant



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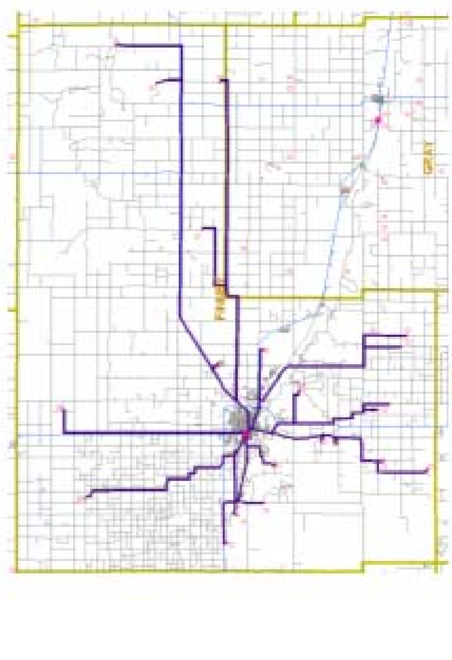

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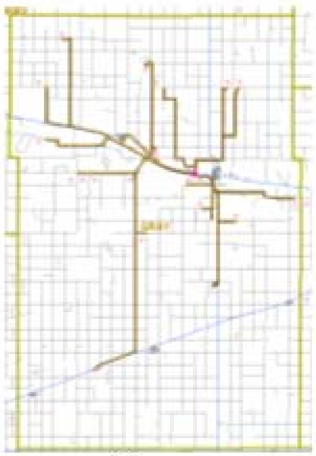

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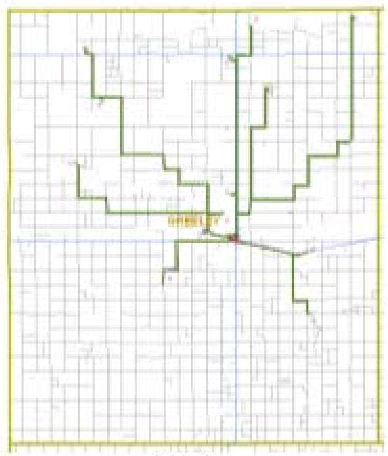

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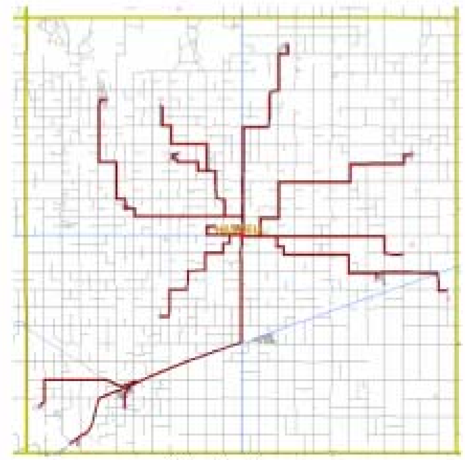

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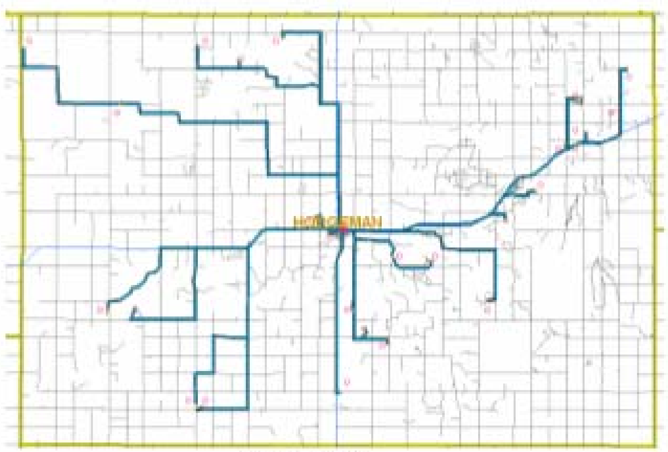

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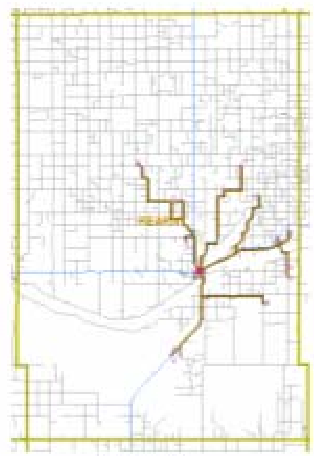

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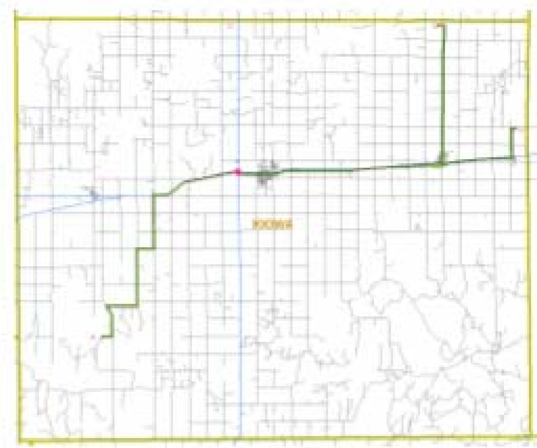
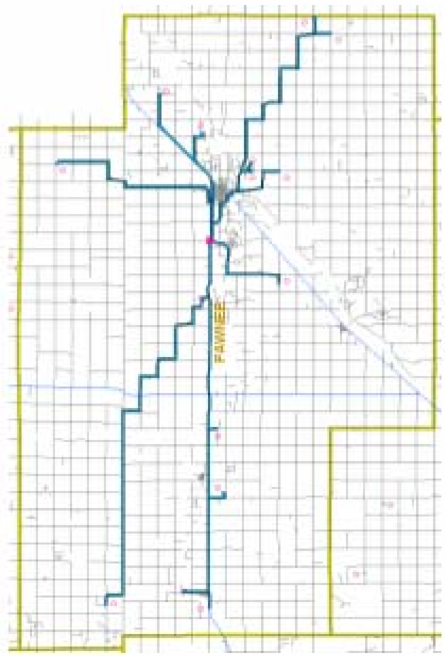


Kiowa

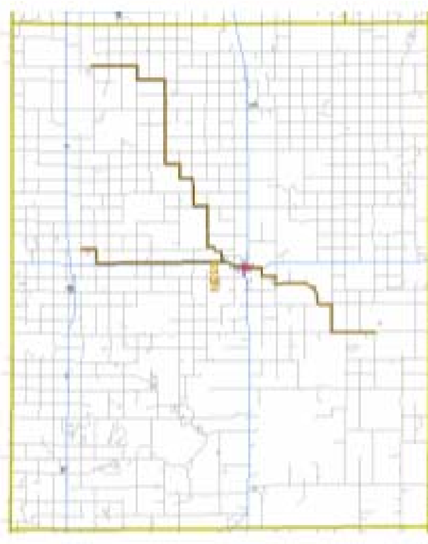
Morton

Meade

Lane



Pawnee



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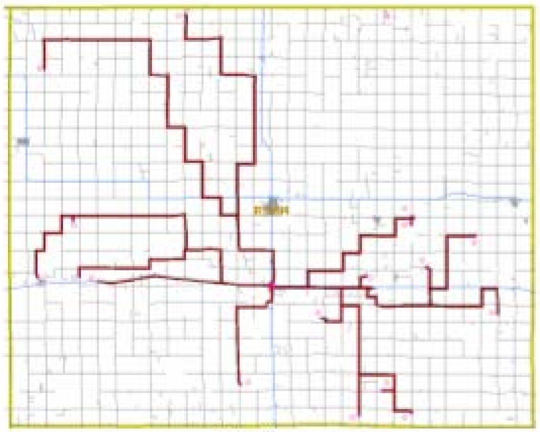

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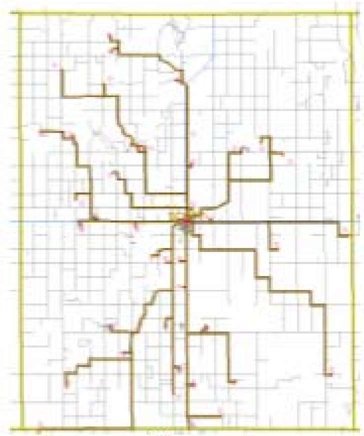
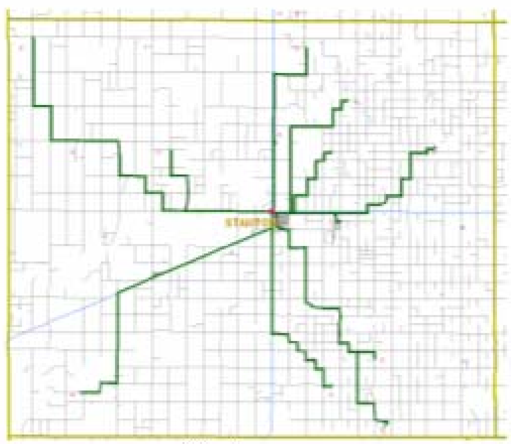


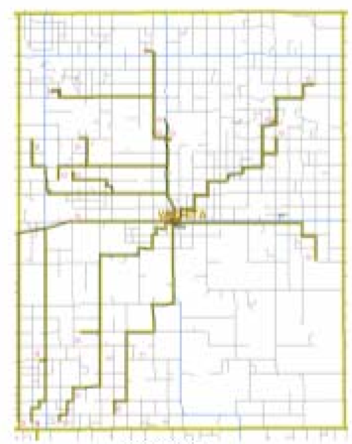
Scott

Seward



Stanton

Stevens



Wichita

APPENDIX II: SHORTEST PATHS FROM ENTRY POINTS IN THE BOUNDARY TO COUNTY CENTROIDS

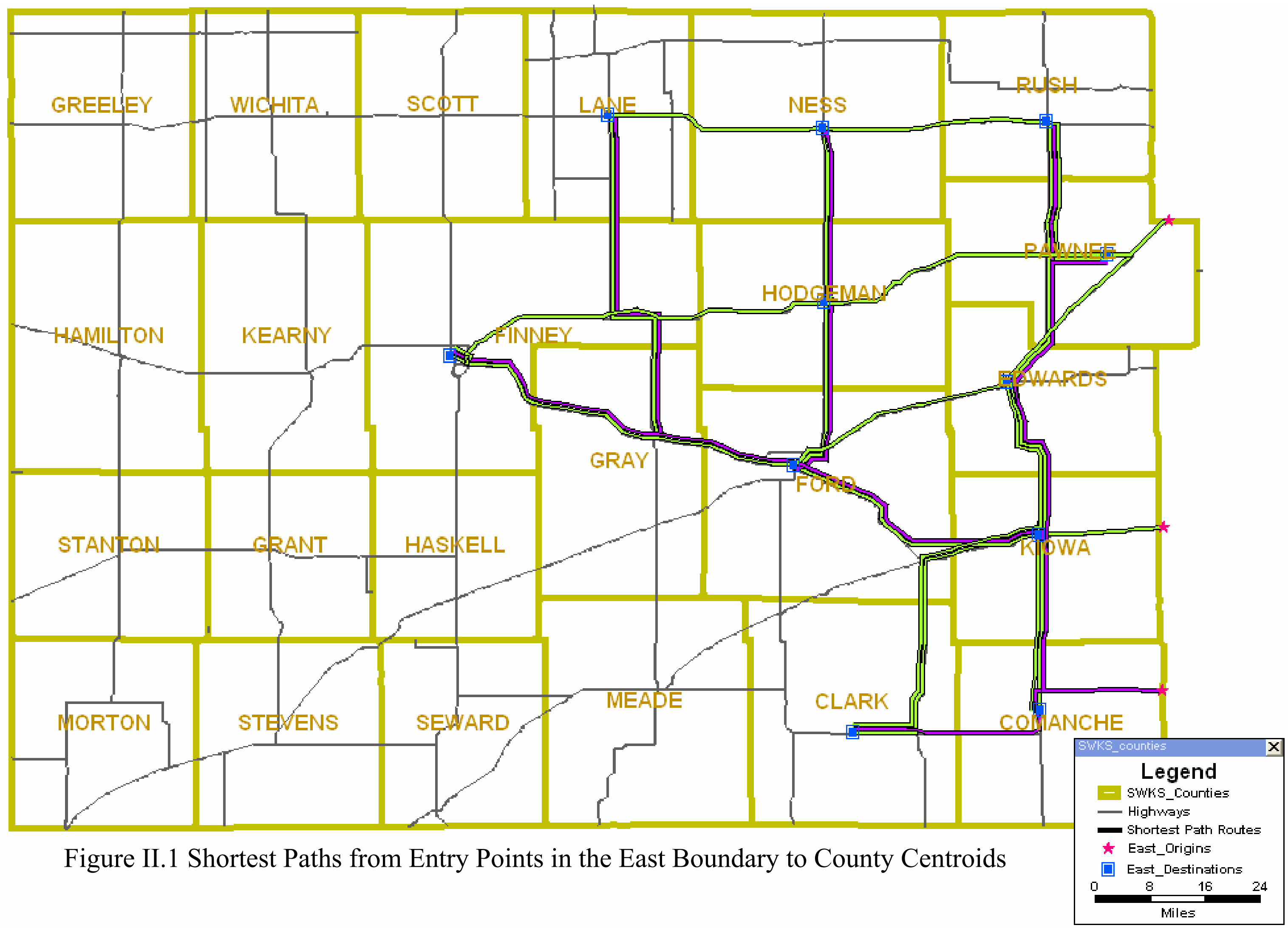


Figure II.1 Shortest Paths from Entry Points in the East Boundary to County Centroids

Table II. 1Highway Mileages from Entry Points in the East Boundary to County Centroids

No.	Origin	Destination	Southwest Kansas Highway Mileage (Miles)																	Other Roads (Miles)	Total Length (Miles)
			East/West Highway										South/North Highway						Total		
			K 4	K 34	US 50	K 51	US 54	US 56	K 96	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	E160	Clark									48.46								48.46	2.67	51.13
2	E160	Comanche									18.93								18.93	1.29	20.22
3	E160	Edwards						0.31			17.98						47.54		65.83	0.89	66.72
4	E160	Finney			46.21		7.47				17.98	25.38				0.10	22.61		119.75	17.78	137.53
5	E160	Ford					7.47				17.98	24.52				22.61			72.58	9.77	82.35
6	E160	Hodgeman			3.18		7.47				17.98	24.52					22.61	20.73	96.49	12.26	108.75
7	E160	Kiowa									17.98						23.21		41.19	0.01	41.20
8	E160	Lane			15.46		17.98				17.98	25.38	51.51			17.98			146.29	9.35	155.64
9	E160	Ness			3.18		7.47				17.98	24.52					22.61	45.05	120.81	13.40	134.21
10	E160	Pawnee						25.26		1.96	17.98						47.54		92.74	2.59	95.33
11	E160	Rush						7.85			17.98						79.32		105.15	0.91	106.06
12	E54	Clark		24.06			34.36				7.91								66.33	4.18	70.51
13	E54	Comanche					16.50				0.95						22.61		40.06	2.55	42.61
14	E54	Edwards					16.50	0.31									24.93		41.74	2.16	43.90
15	E54	Finney			46.21		23.97					25.38				0.10			95.66	19.04	114.70
16	E54	Ford					23.97					24.52							48.49	11.03	59.52
17	E54	Hodgeman			3.18		23.97					25.38						20.73	73.26	12.67	85.93
18	E54	Kiowa					16.50										0.61		17.11	1.27	18.38
19	E54	Lane			15.46		23.97					25.38	51.51						116.32	16.50	132.82
20	E54	Ness			3.18		23.97					24.52						45.05	96.72	14.67	111.39
21	E54	Pawnee					16.50	25.26		1.96							24.93		68.65	3.86	72.51
22	E54	Rush					16.50	7.85									56.71		81.06	2.18	83.24
23	E56	Clark		24.06			17.85	32.64			7.91						24.93		107.39	3.96	111.35
24	E56	Comanche						32.54			0.95						47.54		81.03	2.42	83.45
25	E56	Edwards						33.01											33.01	0.22	33.23
26	E56	Finney			1.26			7.29		70.43			5.98			0.10			85.06	27.65	112.71
27	E56	Ford			31.05			33.86											64.91	2.73	67.64
28	E56	Hodgeman						7.29		44.56								0.15	52.00	2.01	54.01
29	E56	Kiowa						32.54									24.32		56.86	1.14	58.00
30	E56	Lane						7.29	61.46	11.19							19.17		99.11	3.89	103.00
31	E56	Ness						7.29	31.39	11.19							19.17		69.04	2.97	72.01
32	E56	Pawnee						7.29		1.96									9.25	1.46	10.71
33	E56	Rush						7.29		11.96							19.53		38.78	0.69	39.47
Subtotal			0.00	48.12	168.37	0.00	302.42	275.17	92.85	155.21	246.93	249.50	109.00	0.00	0.00	40.89	549.89	131.71	2370.06	210.17	2580.23

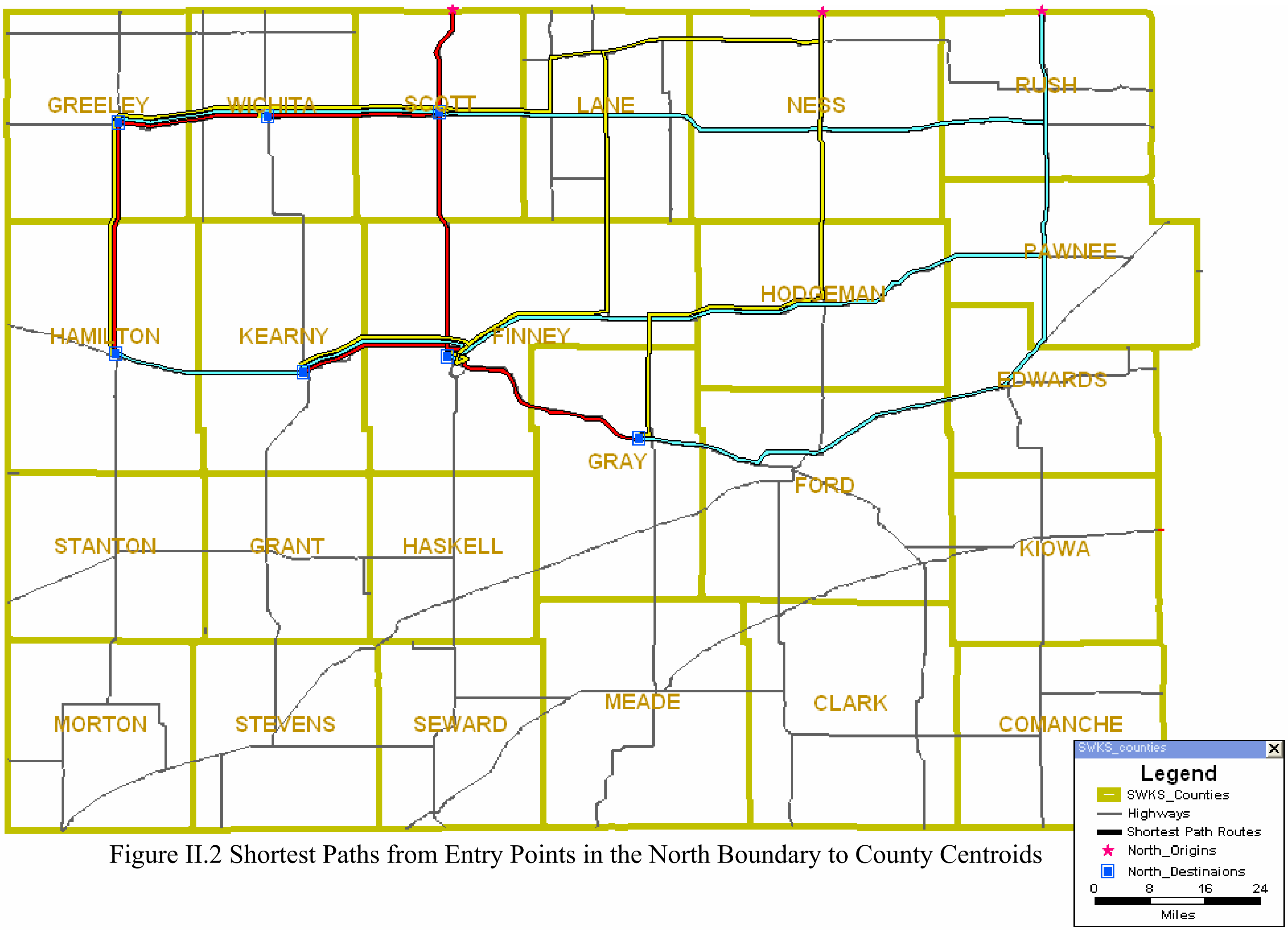


Figure II.2 Shortest Paths from Entry Points in the North Boundary to County Centroids

Table II.2 Highway Mileages from Entry Points in the North Boundary to County Centroids

No.	Origin	Destination	Southwest Kansas Highway Mileage (Miles)																	Other Roads (Miles)	Total Length (Miles)
			East/West Highway										South/North Highway						Total		
			K 4	K 34	US 50	K 51	US 54	US 56	K 96	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	N183	Finney			1.26					59.24			5.98			0.46	30.81		97.75	30.65	128.40
2	N183	Gray			52.16			9.17									43.06		104.39	7.86	112.25
3	N183	Greeley							127.79								11.63		139.42	20.67	160.09
4	N183	Hamilton			42.29					59.24			5.98				30.81		138.32	38.22	176.54
5	N183	Kearny			14.72					59.24			5.98	0.10			30.81		110.85	38.23	149.08
6	N183	Scott							84.08								11.63		95.71	8.27	103.98
7	N183	Wichita							107.17								11.63		118.80	9.61	128.41
8	N283	Finney	31.24		1.26								37.82			0.46		4.20	74.98	26.03	101.01
9	N283	Gray			1.12					25.76			16.84					40.69	84.41	2.88	87.29
10	N283	Greeley	38.68						58.91									4.20	101.79	12.03	113.82
11	N283	Hamilton	38.68						58.91						33.31			4.20	135.10	12.35	147.45
12	N283	Kearny	31.24		14.72								37.33	0.10				4.20	87.59	34.09	121.68
13	N283	Scott	38.68						15.20									4.20	58.08	9.63	67.71
14	N283	Wichita	38.68						38.29									4.20	81.17	10.97	92.14
15	N83	Finney														48.82			48.82	1.87	50.69
16	N83	Gray			31.99											47.27			79.26	4.68	83.94
17	N83	Greeley							43.71							14.99			58.70	3.33	62.03
18	N83	Hamilton							43.71						33.31	14.99			92.01	3.64	95.65
19	N83	Kearny			10.92									0.10		47.27			58.29	12.91	71.20
20	N83	Scott														14.99			14.99	0.54	15.53
21	N83	Wichita							23.09							14.99			38.08	2.26	40.34
Subtotal			217.20	0.00	170.44	0.00	0.00	9.17	600.86	203.48	0.00	0.00	109.93	0.30	66.62	204.24	170.38	65.89	1818.51	290.72	2109.23

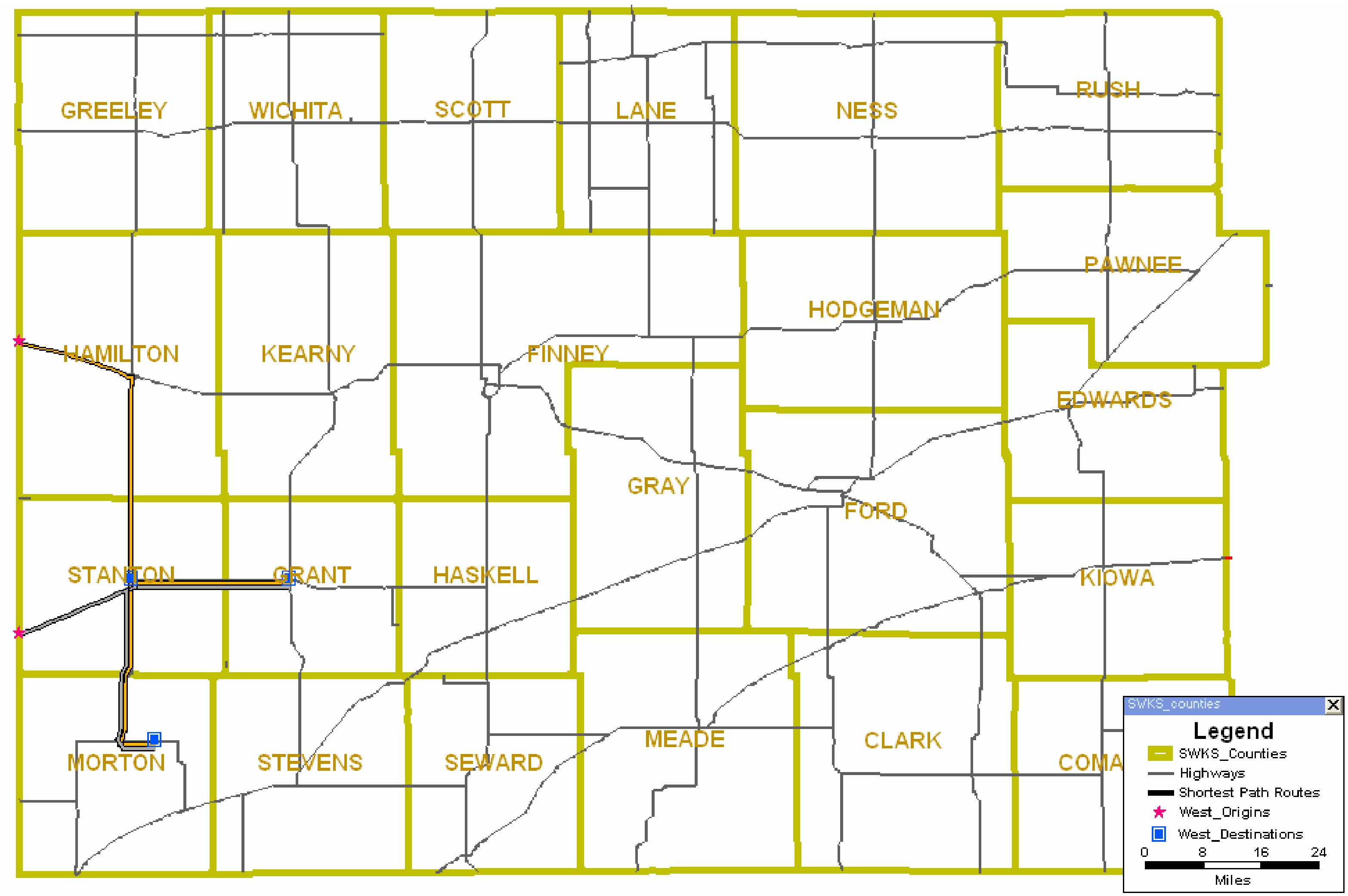


Figure II.3 Shortest Paths from Entry Points in the West Boundary to County Centroids

Table II.3 Highway Mileages from Entry Points in the West Boundary to County Centroids

No.	Origin	Destination	Southwest Kansas Highway Mileage (Miles)																	Other Roads (Miles)	Total Length (Miles)
			East/West Highway										South/North Highway						Total		
			K 4	K 34	US 50	K 51	US 54	US 56	K 96	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	W160	Grant									25.24								25.24	14.53	39.77
2	W160	Morton				4.02					16.09				20.73				40.84	1.84	42.68
3	W160	Stanton									17.09								17.09	0.59	17.68
4	W50/400	Grant			15.08						8.16				27.28				50.52	16.12	66.64
5	W50/400	Morton			15.08	4.02									48.01				67.11	4.44	71.55
6	W50/400	Stanton			15.08										27.28				42.36	2.19	44.55
Subtotal			0.00	0.00	45.24	8.04	0.00	0.00	0.00	0.00	66.58	0.00	0.00	0.00	123.30	0.00	0.00	0.00	243.16	39.71	282.87

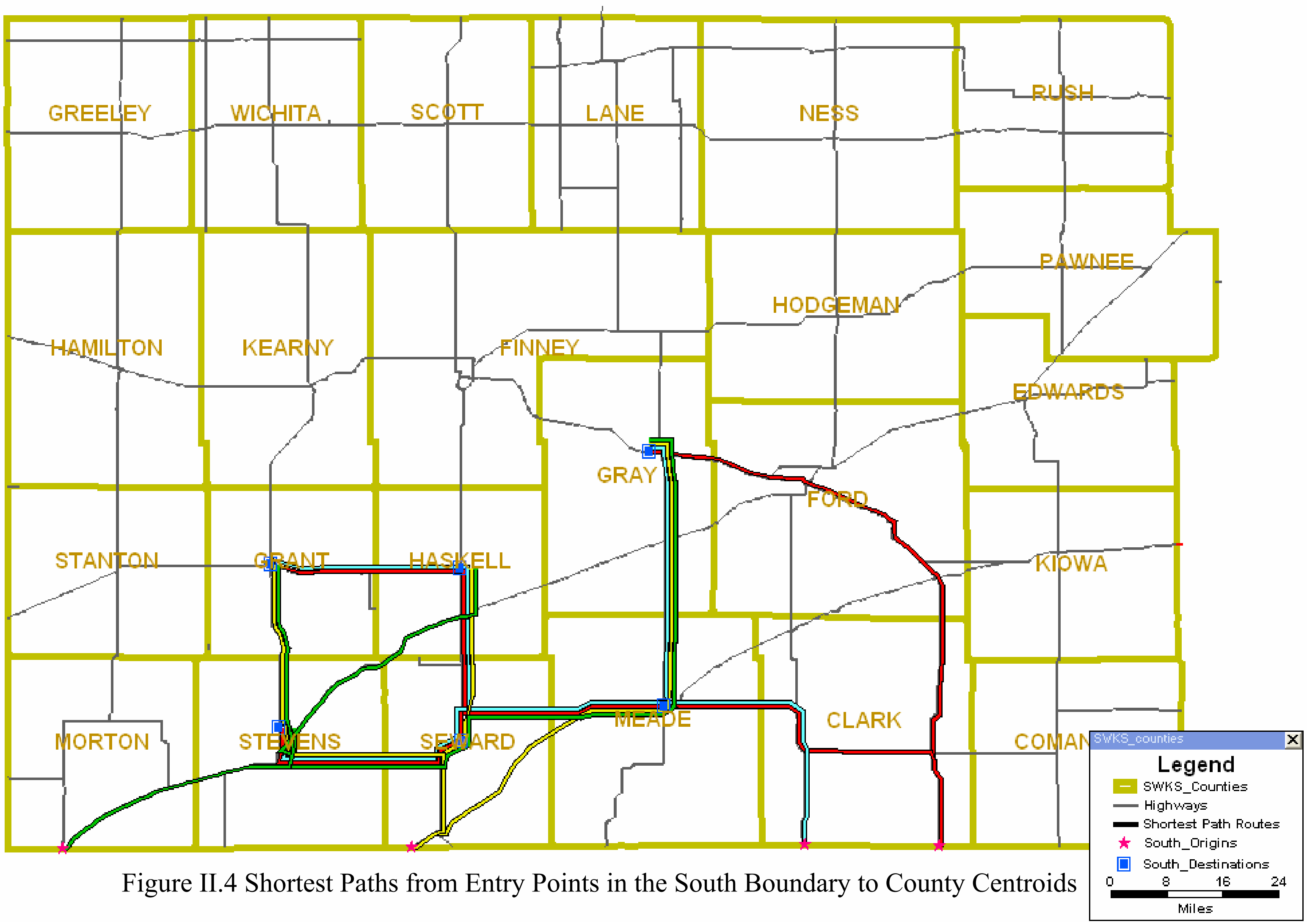


Figure II.4 Shortest Paths from Entry Points in the South Boundary to County Centroids

Table II.4 Highway Mileages from Entry Points in the South Boundary to County Centroids

No.	Origin	Destination	Southwest Kansas Highway Mileage (Miles)																	Other Roads (Miles)	Total Length (Miles)
			East/West Highway										South/North Highway						Total		
			K 4	K 34	US 50	K 51	US 54	US 56	K 96	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	S183	Grant					12.00				66.66					20.05	13.56		112.27	21.94	134.21
2	S183	Gray		29.23	16.58		0.11					20.39					13.56		79.87	6.76	86.63
3	S183	Haskell					12.00				41.33					20.05	13.56		86.94	19.59	106.53
4	S183	Meade									28.46						13.56		42.02	15.33	57.35
5	S183	Seward					12.00				41.33					3.55	13.56		70.44	19.59	90.03
6	S183	Stevens				17.81	12.00	0.89			41.33			2.99		8.84	13.56		97.42	27.52	124.94
7	S283	Grant					12.00				58.00					20.05		12.29	102.34	13.70	116.04
8	S283	Gray			1.12						11.64		23.27					12.29	48.32	28.41	76.73
9	S283	Haskell					12.00				24.51					20.05		12.29	68.85	19.51	88.36
10	S283	Meade									11.64							12.29	23.93	15.26	39.19
11	S283	Seward					12.00				24.51					3.55		12.29	52.35	19.52	71.87
12	S283	Stevens				17.87	12.00	0.89			24.51			2.99		8.84		12.29	79.39	27.38	106.77
13	S54	Grant				17.87	3.72	0.89						22.72		6.85			52.05	15.07	67.12
14	S54	Gray			1.12		41.49						23.27						65.88	15.89	81.77
15	S54	Haskell					3.72									35.73			39.45	3.75	43.20
16	S54	Meade					41.49												41.49	2.73	44.22
17	S54	Seward					3.72										12.04		15.76	3.75	19.51
18	S54	Stevens				17.87	3.72	0.89						2.99		6.85			32.32	11.61	43.93
19	S56	Grant						35.20						22.72					57.92	5.04	62.96
20	S56	Gray			1.12	17.87	12.00	32.50			12.87		23.27			8.84			108.47	24.75	133.22
21	S56	Haskell						65.43								6.02			71.45	3.91	75.36
22	S56	Meade				17.87	12.00	32.50								8.84			71.21	24.46	95.67
23	S56	Seward				17.87		32.50								5.29			55.66	6.72	62.38
24	S56	Stevens						32.50						2.99					35.49	4.28	39.77
Subtotal			0.00	29.23	19.94	125.03	217.97	234.19	0.00	0.00	386.79	20.39	69.81	57.40	0.00	183.40	93.40	73.74	1511.29	356.47	1867.76

APPENDIX III: SHORTEST PATHS FROM COUNTY CENTROIDS TO FOUR MEAT PROCESSING PLANTS IN SOUTHWEST KANSAS

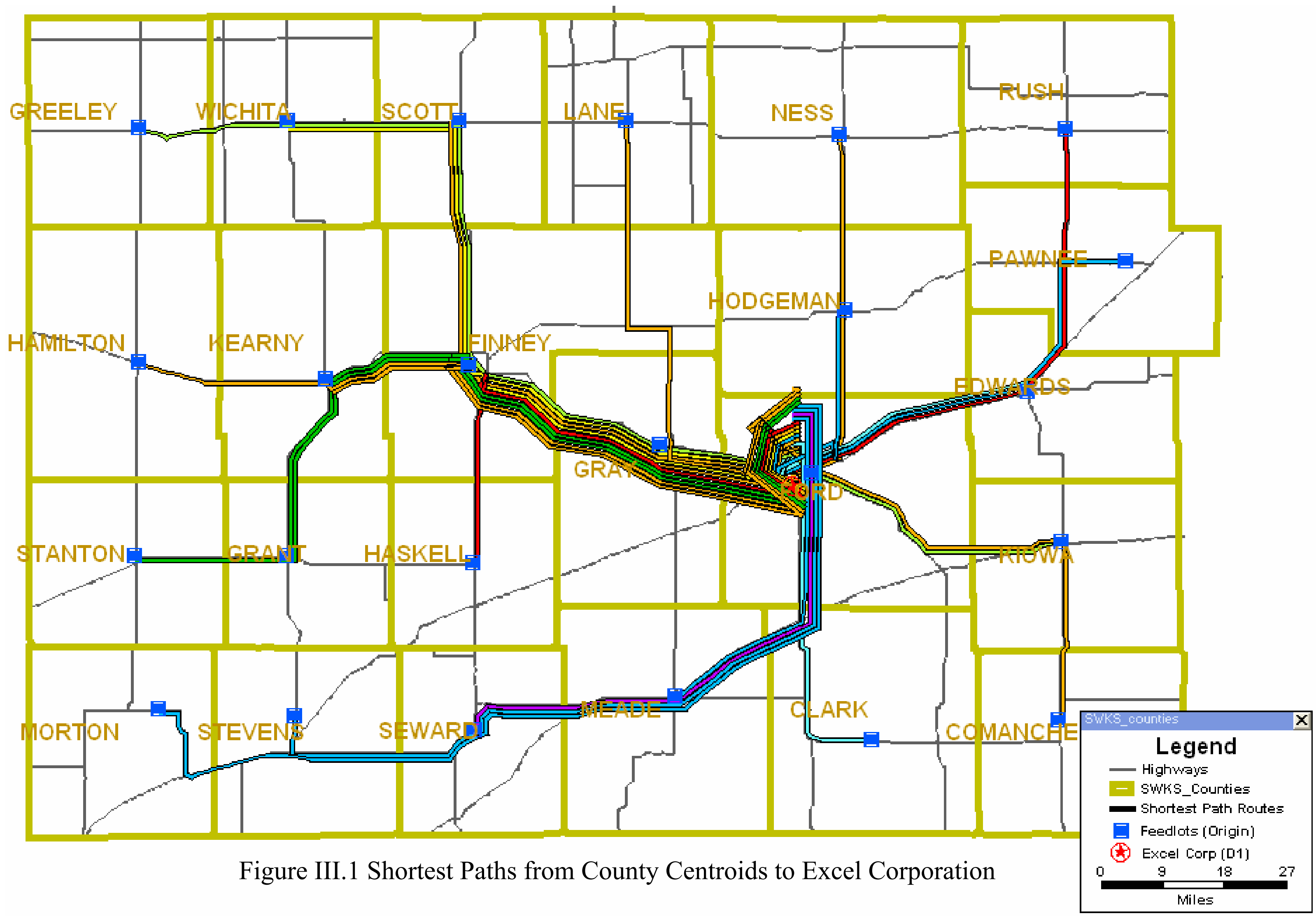


Figure III.1 Shortest Paths from County Centroids to Excel Corporation

Table III.1 Highway Mileages from County Centroids to Excel Corporation

No.	Origin County	Destination	Southwest Kansas Highway Mileage (Miles)															Other Roads (Miles)	Total Length (Miles)
			East/West Highway								South/North Highway						Total		
			US 50	K 51	US 54	US 56	K 96	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	Clark	Excel Corp.				1.00			15.49							30.04	46.53	0.65	47.18
2	Comanche	Excel Corp.			7.47	2.98				24.52					22.61		57.58	13.69	71.27
3	Edwards	Excel Corp.	31.05			3.53											34.58	4.80	39.38
4	Finney	Excel Corp.	46.21			2.98				0.86							50.05	10.40	60.45
5	Ford	Excel Corp.				2.98											2.98	1.88	4.86
6	Grant	Excel Corp.	62.01			1.98				0.86		26.17					91.02	21.14	112.16
7	Gray	Excel Corp.	16.58			2.98				0.86							20.42	7.13	27.55
8	Greeley	Excel Corp.	48.55			2.98	43.71			0.86				32.28			128.38	13.58	141.96
9	Hamilton	Excel Corp.	85.24			2.98				0.86							89.08	22.48	111.56
10	Haskell	Excel Corp.	46.21			2.98				0.86				27.86			77.91	7.51	85.42
11	Hodgeman	Excel Corp.	3.18			2.98		0.11								20.53	26.80	4.89	31.69
12	Kearny	Excel Corp.	62.01			2.98				0.86							65.85	18.39	84.24
13	Kiowa	Excel Corp.			7.47	2.98				24.52							34.97	10.59	45.56
14	Lane	Excel Corp.				2.98				0.86	51.51						55.35	23.24	78.59
15	Meade	Excel Corp.			19.86	1.00										18.93	39.79	2.09	41.88
16	Morton	Excel Corp.		30.70	31.86	16.28								8.84		18.93	106.61	25.73	132.34
17	Ness	Excel Corp.	3.18			2.98										45.05	51.21	5.72	56.93
18	Pawnee	Excel Corp.	31.05			12.15		8.97							12.25		64.42	4.27	68.69
19	Rush	Excel Corp.	31.05			12.15									31.43		74.63	4.27	78.90
20	Scott	Excel Corp.	48.55			2.98				0.86				32.28			84.67	11.09	95.76
21	Seward	Excel Corp.			31.86	1.00								4.02		18.93	55.81	19.53	75.34
22	Stanton	Excel Corp.	62.01			2.98			8.16	0.86		26.17					100.18	33.85	134.03
23	Stevens	Excel Corp.		9.87	31.86	1.89			12.87			2.05		8.84		18.93	86.31	22.51	108.82
24	Wichita	Excel Corp.	48.55			2.98	23.09			0.86				32.28			107.76	12.47	120.23
	Subtotal		625.43	40.57	130.38	95.68	66.80	9.08	36.52	58.50	51.51	54.39	0.00	146.40	66.29	171.34	1552.89	301.89	1854.78

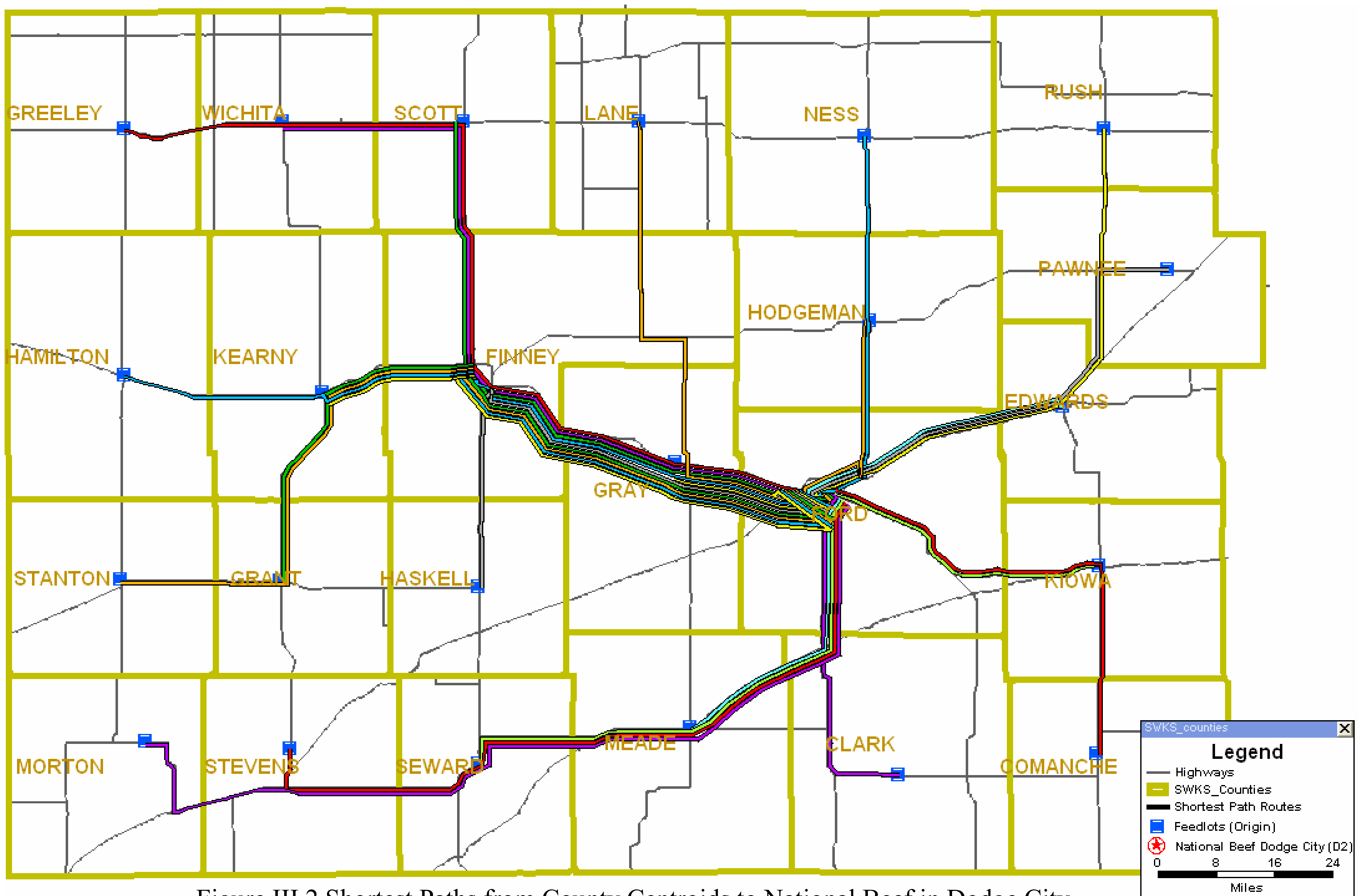


Figure III.2 Shortest Paths from County Centroids to National Beef in Dodge City

Table III.2 Highway Mileages from County Centroids to National Beef in Dodge City

No.	Origin County	Destination	Southwest Kansas Highway Mileage (Miles)															Other Roads (Miles)	Total Length (Miles)
			East/West Highway								South/North Highway						Total		
			US 50	K 51	US 54	US 56	K 96	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	Clark	NB Dodge City				1.98			15.49							30.04	47.51	2.28	49.79
2	Comanche	NB Dodge City			7.47				1.82	24.52					22.61		56.42	10.29	66.71
3	Edwards	NB Dodge City	31.05			0.55											31.60	3.17	34.77
4	Finney	NB Dodge City	46.21							0.86							47.07	8.77	55.84
5	Ford	NB Dodge City															0.00	0.25	0.25
6	Grant	NB Dodge City	51.09							0.86		26.17					78.12	29.43	107.55
7	Gray	NB Dodge City	16.58							0.86							17.44	5.50	22.94
8	Greeley	NB Dodge City	51.09				43.71			0.86				32.28			127.94	9.41	137.35
9	Hamilton	NB Dodge City	88.78							0.86							89.64	17.31	106.95
10	Haskell	NB Dodge City	46.21							0.86				27.86			74.93	5.88	80.81
11	Hodgeman	NB Dodge City	3.18					0.11								20.53	23.82	3.26	27.08
12	Kearny	NB Dodge City	51.09							0.86							51.95	27.68	79.63
13	Kiowa	NB Dodge City			7.47					24.52							31.99	9.00	40.99
14	Lane	NB Dodge City								0.86	51.51						52.37	21.61	73.98
15	Meade	NB Dodge City			19.86	1.98										18.93	40.77	3.72	44.49
16	Morton	NB Dodge City		30.70	31.86	17.26			12.87					8.84		18.93	120.46	14.49	134.95
17	Ness	NB Dodge City	3.18													45.05	48.23	4.09	52.32
18	Pawnee	NB Dodge City	31.05			9.17		8.97							12.25		61.44	2.64	64.08
19	Rush	NB Dodge City	31.05			9.17									31.43		71.65	2.64	74.29
20	Scott	NB Dodge City	51.09							0.86				32.28			84.23	6.92	91.15
21	Seward	NB Dodge City			31.86	1.98			12.87					4.02		18.93	69.66	8.29	77.95
22	Stanton	NB Dodge City	59.47						8.16	0.86		26.17					94.66	34.76	129.42
23	Stevens	NB Dodge City		17.87	31.86	2.87			12.87			2.05		8.84		18.93	95.29	16.14	111.43
24	Wichita	NB Dodge City	51.09				23.09			0.86				32.28			107.32	8.30	115.62
	Subtotal		612.21	48.57	130.38	44.96	66.80	9.08	64.08	58.50	51.51	54.39	0.00	146.40	66.29	171.34	1524.51	255.83	1780.34

Note: NB: National Beef Packing Co. LLC

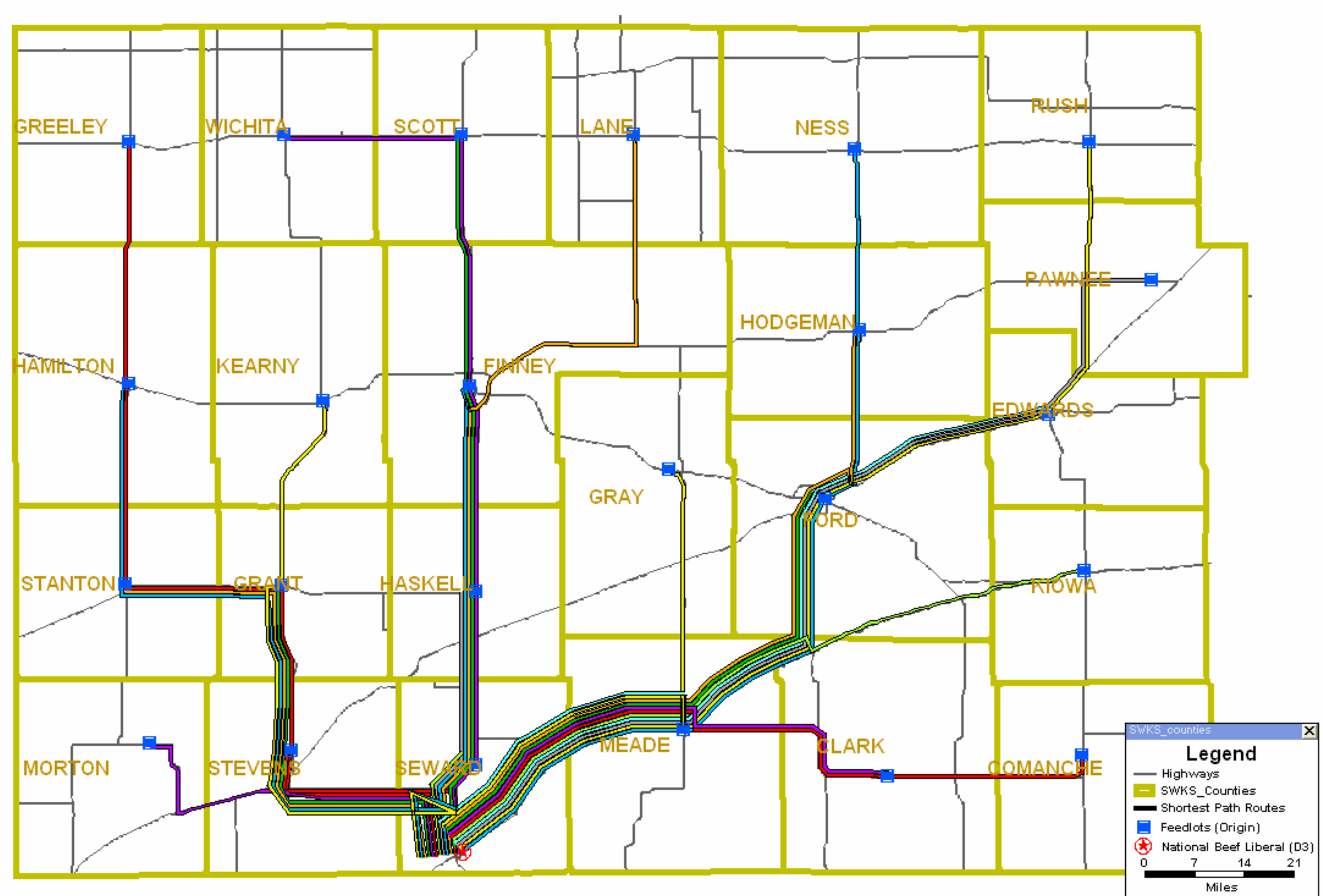


Figure III.3 Shortest Paths from County Centroids to National Beef in Liberal

Table III.3 Highway Mileages from County Centroids to National Beef in Liberal

No.	Origin County	Destination	Southwest Kansas Highway Mileage (Miles)															Other Roads (Miles)	Total Length (Miles)
			East/West Highway								South/North Highway						Total		
			US 50	K 51	US 54	US 56	K 96	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	Clark	NB Liberal			37.37				20.56								57.93	14.15	72.08
2	Comanche	NB Liberal			37.37				49.21								86.58	15.54	102.12
3	Edwards	NB Liberal	31.05		57.23	2.53										18.93	109.74	7.39	117.13
4	Finney	NB Liberal			0.40									63.37			63.77	5.53	69.30
5	Ford	NB Liberal			57.23	1.98										18.93	78.14	4.47	82.61
6	Grant	NB Liberal		17.87	0.40	0.89						22.72		6.85			48.73	14.38	63.11
7	Gray	NB Liberal	1.12		37.37						34.21						72.70	3.02	75.72
8	Greeley	NB Liberal		17.87	0.40	0.89			8.16			22.72	60.59	6.85			117.48	29.58	147.06
9	Hamilton	NB Liberal		17.87	0.40	0.89			8.16			22.72	27.28	6.85			84.17	28.74	112.91
10	Haskell	NB Liberal			0.40									35.73			36.13	3.51	39.64
11	Hodgeman	NB Liberal			57.23			0.11								39.46	96.80	12.64	109.44
12	Kearny	NB Liberal		17.87	0.40	0.89						48.89		6.85			74.90	16.14	91.04
13	Kiowa	NB Liberal			97.19												97.19	2.65	99.84
14	Lane	NB Liberal	1.49		0.40						28.69			63.59			94.17	26.62	120.79
15	Meade	NB Liberal			37.37												37.37	0.50	37.87
16	Morton	NB Liberal		22.61	0.40	15.28								6.85			45.14	17.80	62.94
17	Ness	NB Liberal	3.18		57.23	1.98										45.05	107.44	27.25	134.69
18	Pawnee	NB Liberal	31.05		57.23	11.15		8.97							12.25	18.93	139.58	6.86	146.44
19	Rush	NB Liberal	31.05		57.23	11.15									31.34	18.93	149.70	6.95	156.65
20	Scott	NB Liberal			0.40									97.65			98.05	6.67	104.72
21	Seward	NB Liberal			0.40									11.67			12.07	3.50	15.57
22	Stanton	NB Liberal		17.87	0.40	0.89			8.16			22.72		6.85			56.89	28.10	84.99
23	Stevens	NB Liberal		17.87	0.40	0.89						2.05		6.85			28.06	11.36	39.42
24	Wichita	NB Liberal			0.40		23.09							97.65			121.14	8.05	129.19
	Subtotal		98.94	129.83	595.25	49.41	23.09	9.08	94.25	0.00	62.90	141.82	87.87	417.61	43.59	160.23	1913.87	301.41	2215.28

Note: NB: National Beef Packing Co. LLC

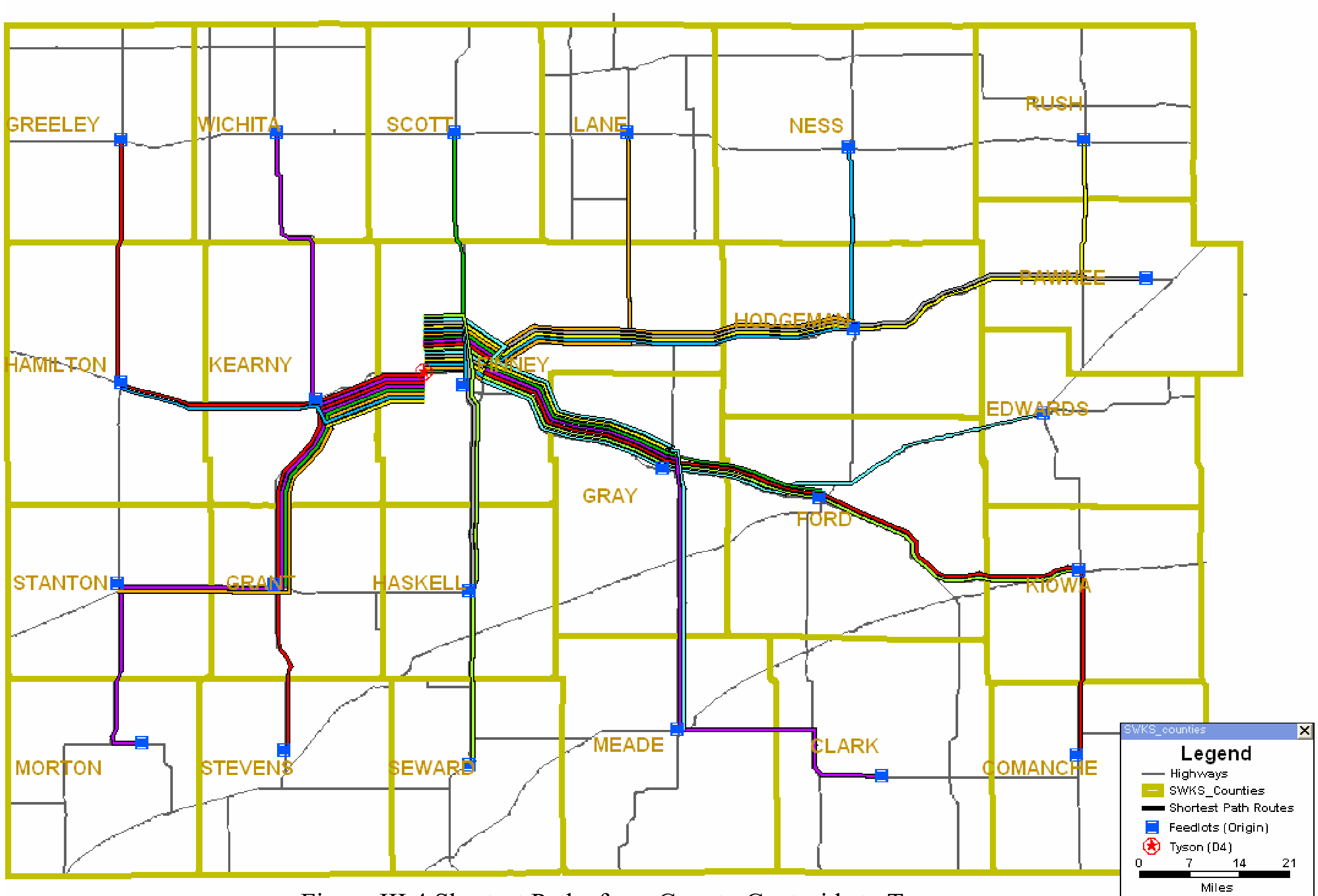


Figure III.4 Shortest Paths from County Centroids to Tyson

Table III.4 Highway Mileages from County Centroids to Tyson and Summary

No.	Origin County	Destination	Southwest Kansas Highway Mileage (Miles)															Other Roads (Miles)	Total Length (Miles)
			East/West Highway								South/North Highway						Total		
			US 50	K 51	US 54	US 56	K 96	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	Clark	Tyson	36.63						20.56		23.27						80.46	31.93	112.39
2	Comanche	Tyson	49.55		7.47				1.82	25.38					22.61		106.83	23.14	129.97
3	Edwards	Tyson	87.88			0.55											88.43	8.52	96.95
4	Finney	Tyson	1.00											2.00			3.00	4.53	7.53
5	Ford	Tyson	52.09							0.86							52.95	10.07	63.02
6	Grant	Tyson	9.92									26.17					36.09	8.19	44.28
7	Gray	Tyson	35.51														35.51	4.82	40.33
8	Greeley	Tyson	36.69										33.31				70.00	7.84	77.84
9	Hamilton	Tyson	36.69														36.69	6.99	43.68
10	Haskell	Tyson	1.00											29.64			30.64	6.55	37.19
11	Hodgeman	Tyson	4.80					25.96			5.98						36.74	26.76	63.50
12	Kearny	Tyson	9.92														9.92	6.44	16.36
13	Kiowa	Tyson	49.55		7.47					25.38							82.40	21.86	104.26
14	Lane	Tyson	4.80								28.69						33.49	27.26	60.75
15	Meade	Tyson	36.63								23.27						59.90	18.28	78.18
16	Morton	Tyson	9.91	4.02					9.16			26.17	20.73				69.99	23.17	93.16
17	Ness	Tyson	4.80					25.76			5.98					24.42	60.96	27.70	88.66
18	Pawnee	Tyson	4.80					68.21			5.98						78.99	27.26	106.25
19	Rush	Tyson	4.80					59.24			5.98				18.17		88.19	28.26	116.45
20	Scott	Tyson	1.00											32.28			33.28	5.68	38.96
21	Seward	Tyson	1.00											53.71			54.71	6.55	61.26
22	Stanton	Tyson	9.92						8.16			26.17					44.25	21.91	66.16
23	Stevens	Tyson	9.92									46.74					56.66	11.32	67.98
24	Wichita	Tyson	9.92									40.71					50.63	6.99	57.62
	Subtotal		508.73	4.02	14.94	0.55	0.00	179.17	39.70	51.62	99.15	165.96	54.04	117.63	40.78	24.42	1300.71	372.04	1672.75
	Total		**1845.31**	**222.99**	**870.95**	**190.60**	**156.69**	**206.41**	**234.55**	**168.62**	**265.07**	**416.56**	**141.91**	**828.04**	**216.95**	**527.33**	**6291.98**	**1231.17**	**7523.15**

APPENDIX IV: SHORTEST PATHS FROM ENTRY POINTS TO FOUR MEAT PROCESSING PLANTS IN SOUTHWEST KANSAS

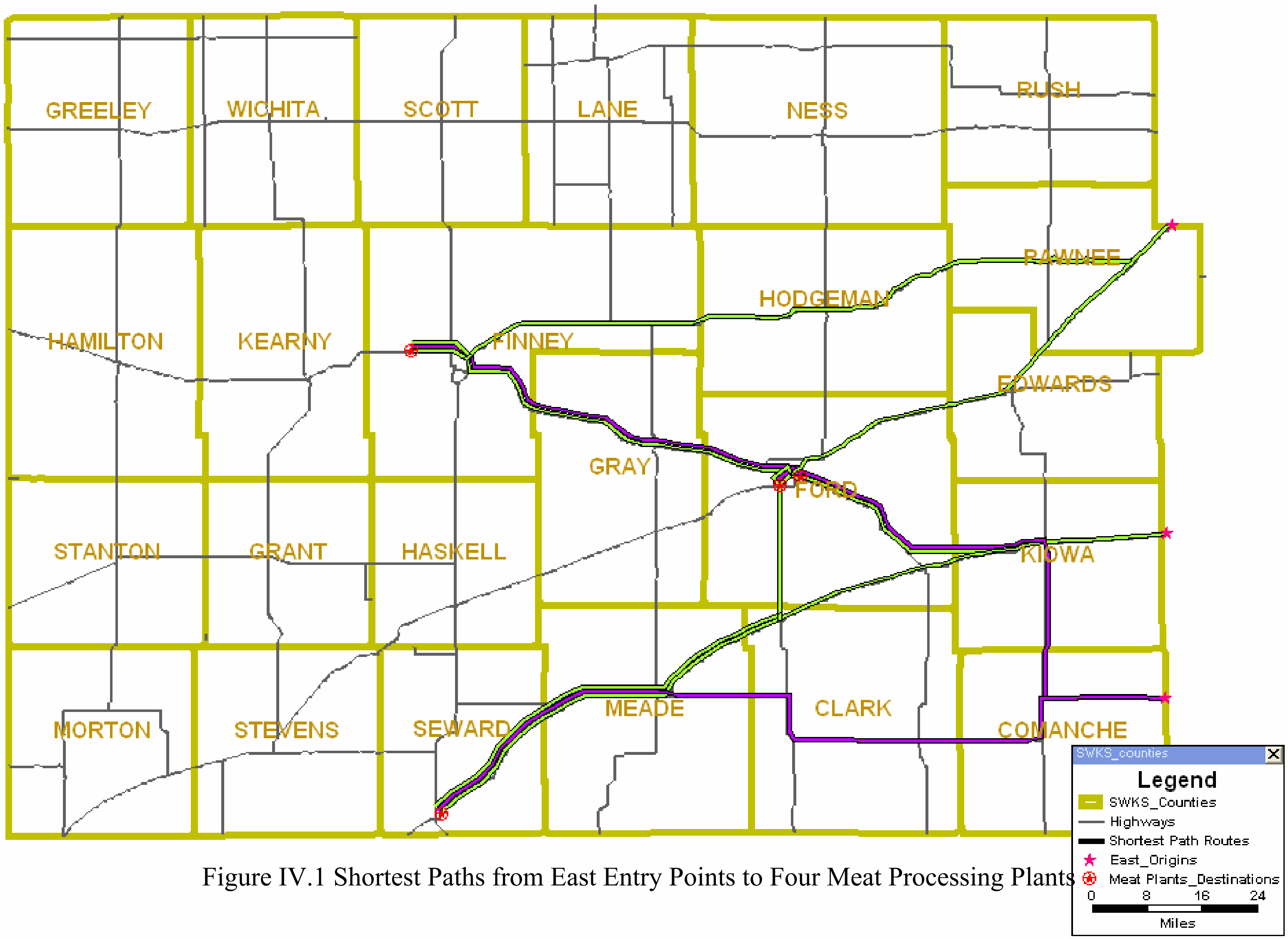


Figure IV.1 Shortest Paths from East Entry Points to Four Meat Processing Plants

Table IV.1 Highway Mileages from East Entry Points to Four Meat Processing Plants

No.	Origin	Destination	Southwest Kansas Highway Mileage (Miles)																Other Roads (Miles)	Total Length (Miles)
			East/West Highway									South/North Highway						Total		
			K 4	K 34	US 50	K 51	US 54	US 56	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	E54	Excel					23.97	1.98			24.52							50.47	11.85	62.32
2		NB Dodge City					23.97				24.29							48.26	9.46	57.72
3		NB Liberal					113.70											113.70	3.91	117.61
4		Tyson			52.09		23.97				24.29							100.35	21.67	122.02
5	E160	Excel					7.47			17.98	24.29					22.61		72.35	12.80	85.15
6		NB Dodge City					7.47			17.98	24.29					22.61		72.35	8.19	80.54
7		NB Liberal					37.37			69.01								106.38	16.83	123.21
8		Tyson			52.09		7.47			17.98	24.52					22.61		124.67	20.18	144.85
9	E56	Excel			31.05			35.84										66.89	4.50	71.39
10		NB Dodge City			31.05			35.84			0.23							67.12	1.70	68.82
11		NB Liberal			31.05		57.23	35.84									18.93	143.05	7.09	150.14
12		Tyson			4.80			7.29	70.43			5.98						88.50	28.72	117.22
Subtotal			0.00	0.00	202.13	0.00	302.62	116.79	70.43	122.95	146.43	5.98	0.00	0.00	0.00	67.83	18.93	1054.09	146.90	1200.99

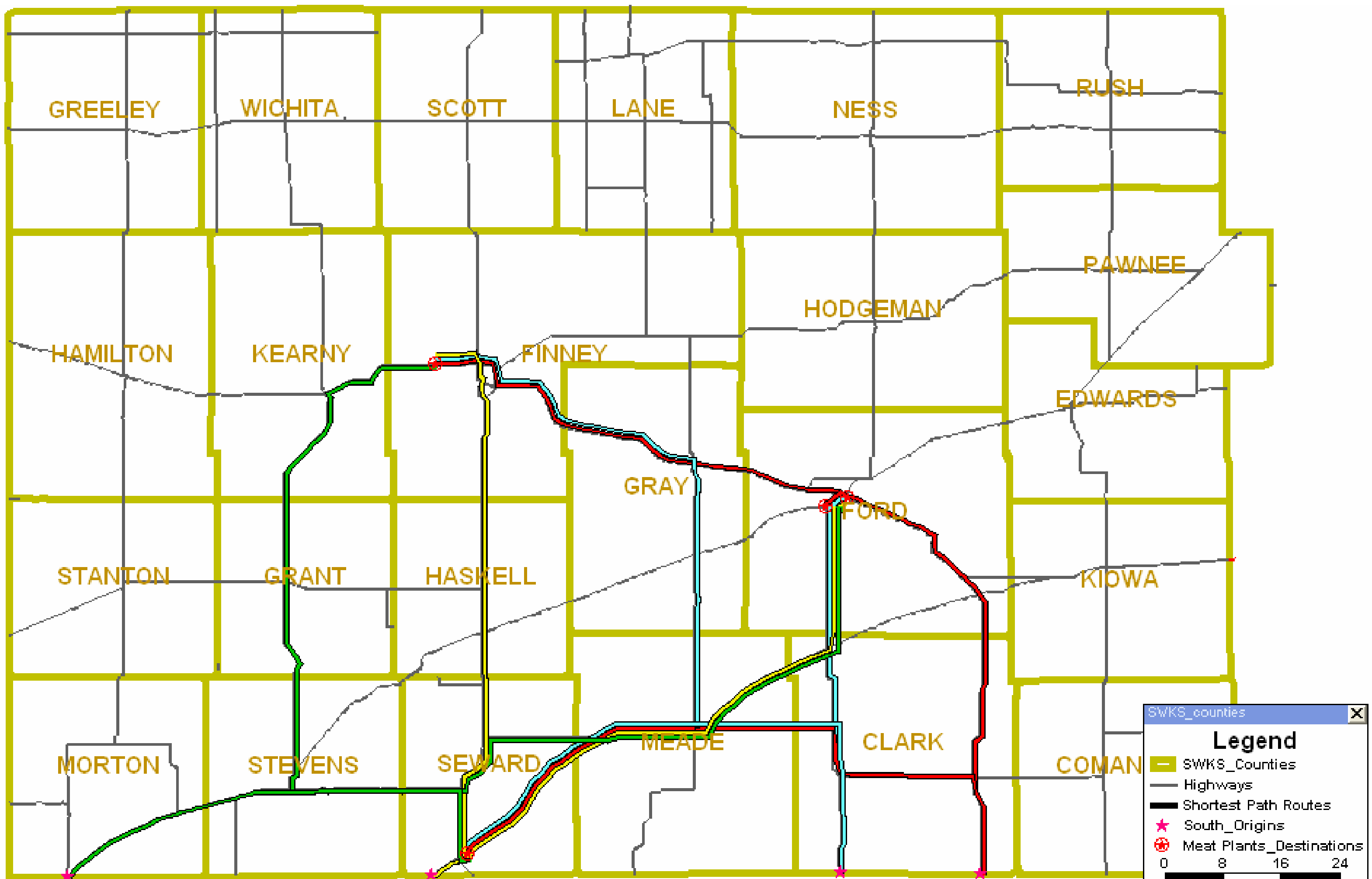


Figure IV. 2 Shortest Paths from South Entry Points to Four Meat Processing Plants

Table IV.2 Highway Mileages from South Entry Points to Four Meat Processing Plants

No.	Origin	Destination	Southwest Kansas Highway Mileage (Miles)																Other Roads (Miles)	Total Length (Miles)
			East/West Highway									South/North Highway						Total		
			K 4	K 34	US 50	K 51	US 54	US 56	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	S54	Excel					61.35										18.93	80.28	4.52	84.80
2		NB Dodge City					61.35	1.98			0.23						18.93	82.49	6.91	89.40
3		NB Liberal					4.12											4.12	1.93	6.05
4		Tyson			1.00		3.72								65.37			70.09	10.31	80.40
5	S283	Excel								6.58							42.33	48.91	1.94	50.85
6		NB Dodge City								6.58	0.23						42.33	49.14	6.32	55.46
7		NB Liberal					37.37			11.64							12.29	61.30	15.45	76.75
8		Tyson			36.63					11.64		23.27					12.29	83.83	33.23	117.06
9	S56	Excel				17.87	31.86	33.50		12.87					8.84		18.93	123.87	12.38	136.25
10		NB Dodge City				17.87	31.86	34.48		12.87	0.23				8.84		18.93	125.08	15.77	140.85
11		NB Liberal				17.87	0.40	32.50							6.85			57.62	10.23	67.85
12		Tyson			9.92			33.50					48.89					92.31	14.49	106.80
13	S183	Excel		27.62			0.11				19.30					13.56		60.59	6.67	67.26
14		NB Dodge City		27.62			0.11				19.30					13.56		60.59	2.06	62.65
15		NB Liberal					37.37			28.46						13.56		79.39	15.53	94.92
16		Tyson		27.62	52.09						19.30					13.56		112.57	14.39	126.96
Subtotal			0.00	82.86	99.64	53.61	269.62	135.96	0.00	90.64	58.59	23.27	48.89	0.00	89.90	54.24	184.96	1192.18	172.13	1364.31

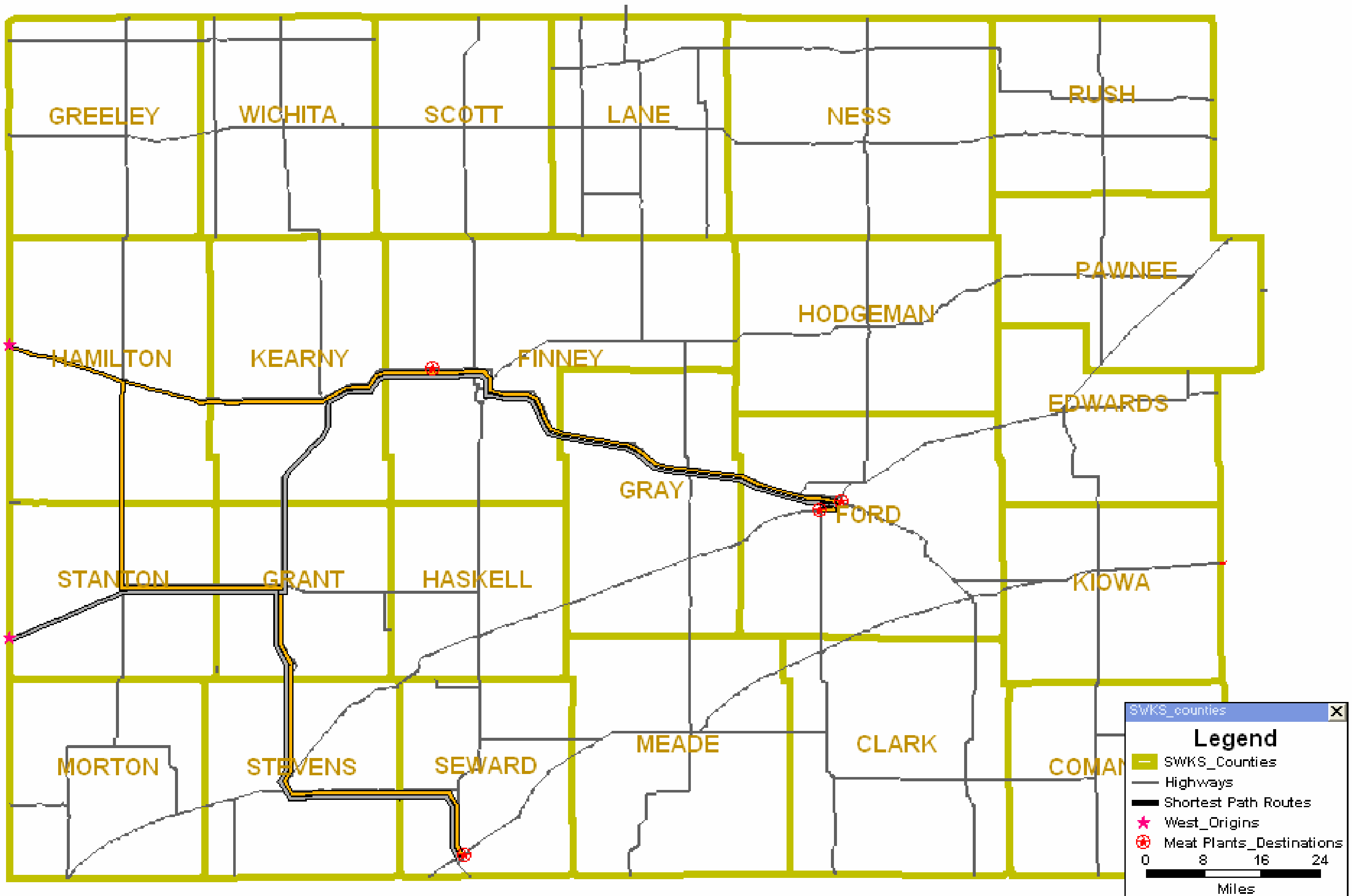


Figure IV.3 Shortest Paths from West Entry Points to Four Meat Processing Plants

Table IV.3 Highway Mileages from West Entry Points to Four Meat Processing Plants

No.	Origin	Destination	Southwest Kansas Highway Mileage (Miles)																Other Roads (Miles)	Total Length (Miles)
			East/West Highway									South/North Highway						Total		
			K 4	K 34	US 50	K 51	US 54	US 56	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	W160	Excel			61.01			1.98		25.24	0.86		26.17					115.26	35.45	150.71
2		NB Dodge City			61.01					25.24	1.09		26.17					113.51	34.63	148.14
3		NB Liberal				17.87	0.40	0.89		25.24			22.72		6.85			73.97	28.70	102.67
4		Tyson			9.92					25.24			26.17					61.33	22.51	83.84
5	W50	Excel			103.86						0.86							104.72	22.47	127.19
6		NB Dodge City			98.80						1.09							99.89	24.73	124.62
7		NB Liberal			15.08	17.87	0.40	0.89		8.16			22.72	27.28	6.58			98.98	30.56	129.54
8		Tyson			51.77													51.77	8.55	60.32
Subtotal			0.00	0.00	401.45	35.74	0.80	3.76	0.00	109.12	3.90	0.00	123.95	27.28	13.43	0.00	0.00	719.43	207.60	927.03

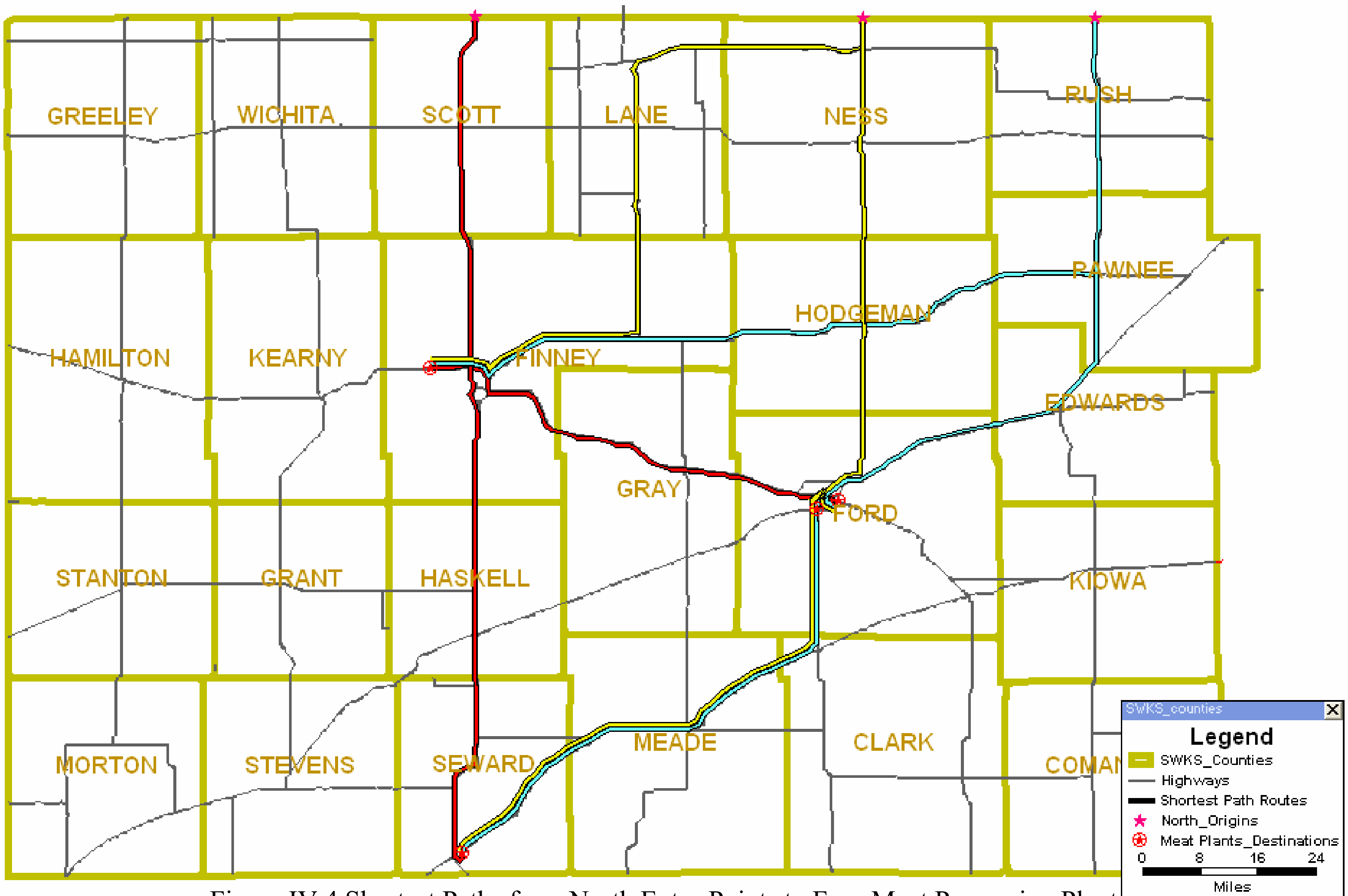


Figure IV.4 Shortest Paths from North Entry Points to Four Meat Processing Plants

Table IV.4 Highway Mileages from North Entry Points to Four Meat Processing Plants and Summary

No.	Origin	Destination	Southwest Kansas Highway Mileage (Miles)																Other Roads (Miles)	Total Length (Miles)
			East/West Highway									South/North Highway						Total		
			K 4	K 34	US 50	K 51	US 54	US 56	K 156	US 160	US 400	K 23	K 25	K 27	US 83	US 183	US 283			
1	N183	Excel			31.05			11.15								43.06		85.26	8.74	94.00
2		NB Dodge City			31.05			9.17			0.23					43.06		83.51	7.92	91.43
3		NB Liberal			31.05		57.23	11.15								43.06	18.93	161.42	11.33	172.75
4		Tyson			4.80				59.24			5.98				30.81		100.83	31.73	132.56
5	N283	Excel			3.18			1.98									61.32	66.48	6.35	72.83
6		NB Dodge City			3.18						0.23						61.32	64.73	5.53	70.26
7		NB Liberal			3.18		57.23	1.98									61.32	123.71	27.87	151.58
8		Tyson	30.74		4.80							37.33					4.20	77.07	28.09	105.16
9	N83	Excel			48.57			1.98			0.86				47.27			98.68	11.81	110.49
10		NB Dodge City			48.57						1.09				47.27			96.93	10.99	107.92
11		NB Liberal					0.40								112.64			113.04	7.41	120.45
12		Tyson			1.00										47.27			48.27	6.41	54.68
Total			**30.74**	**82.86**	**913.65**	**89.35**	**687.90**	**293.92**	**129.67**	**322.71**	**211.33**	**72.56**	**172.84**	**27.28**	**357.78**	**282.06**	**410.98**	**4085.63**	**690.81**	**4776.44**

APPENDIX V: SHORTEST PATHS FROM FOUR MEAT PROCESSING PLANTS TO U.S. CITIES

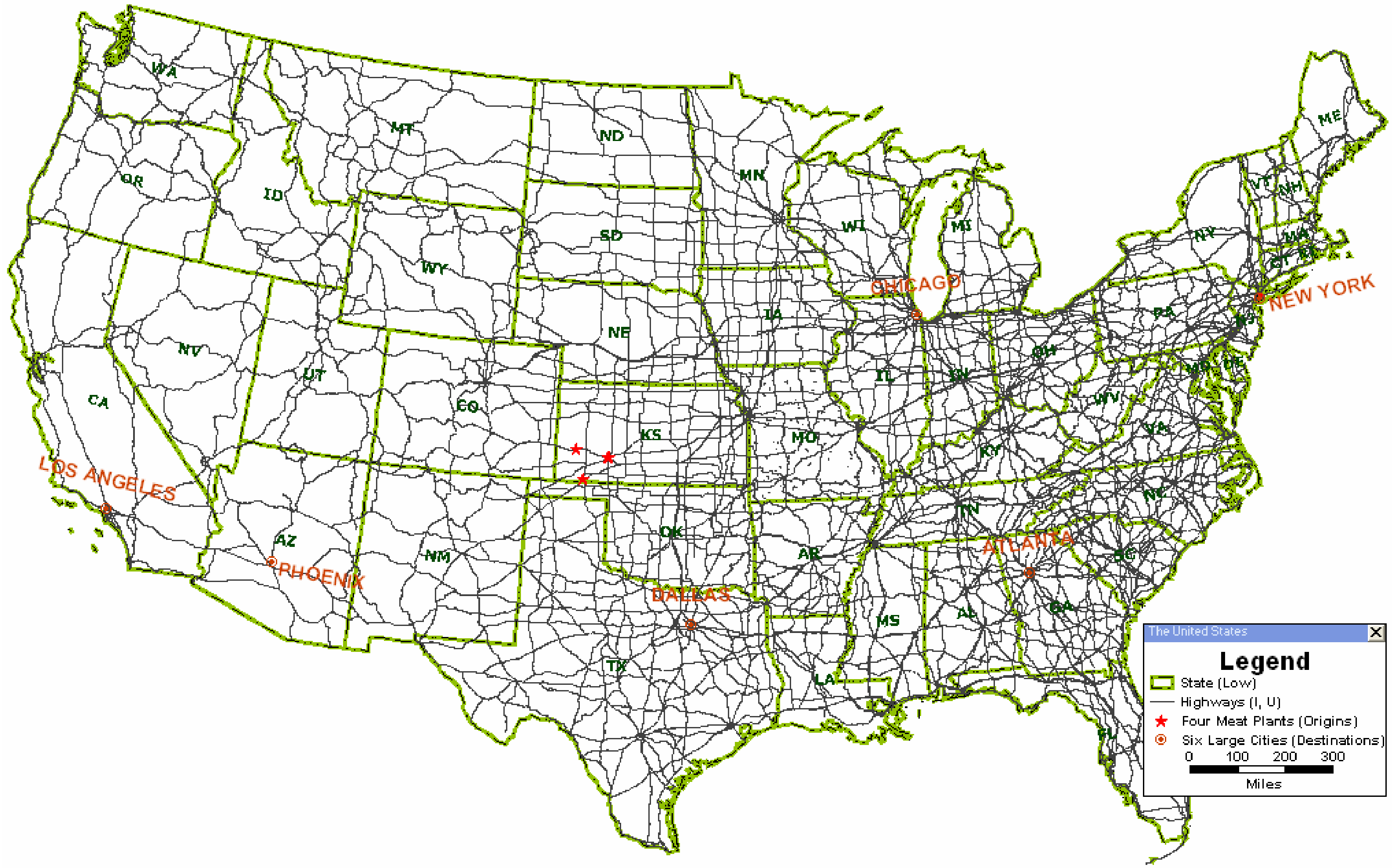


Figure V.1 Map of Meat Processing Plants (Origins) and Six US cities (Destinations)

Figure V.2 Shortest Paths from Four Meat Processing Plants to Six US Cities

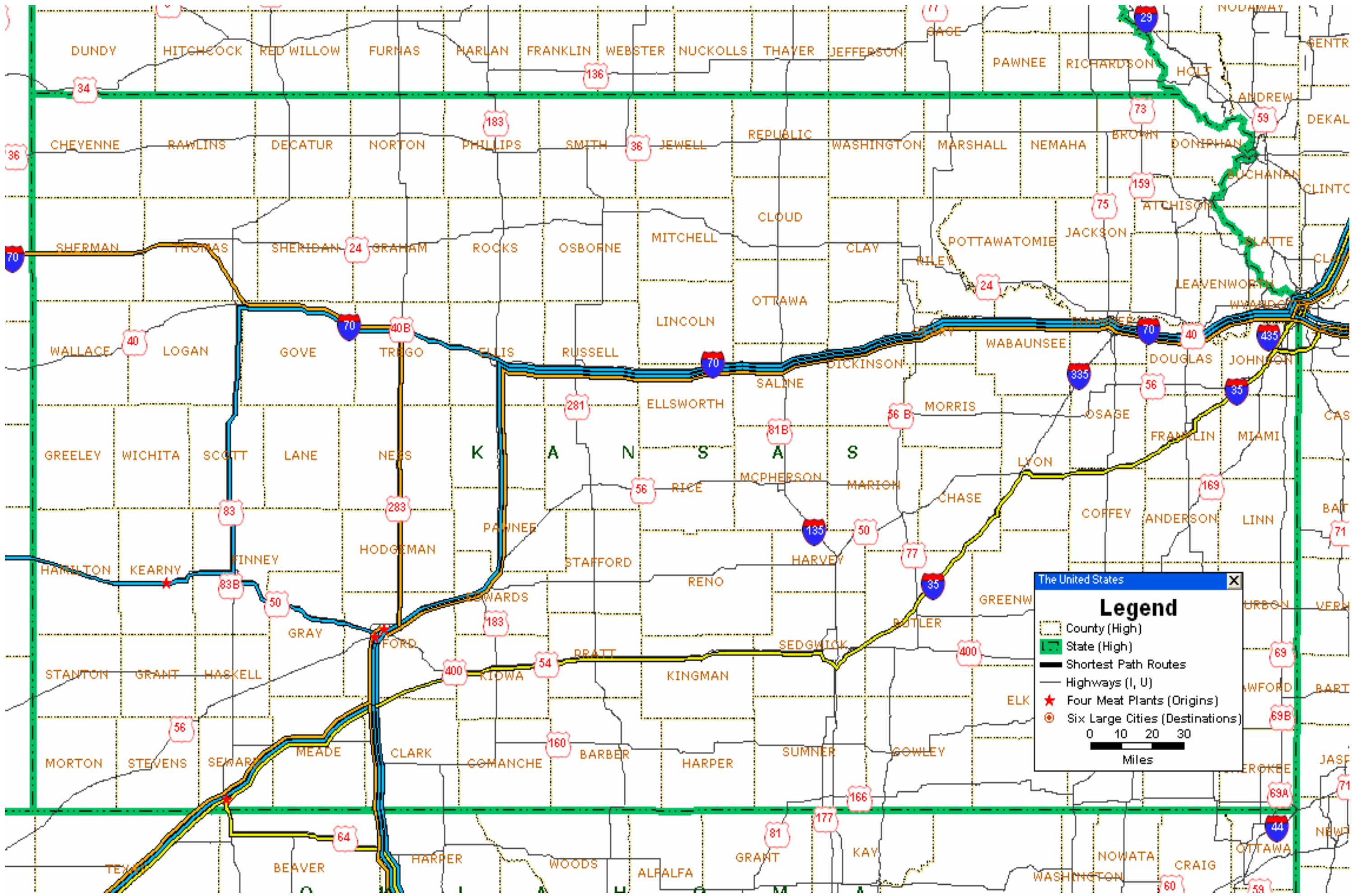


Figure V.3 Shortest Paths from Four Meat Processing Plants to Six US Cities (Kansas Part)

Table V.1 Highway Mileages from Four Meat Processing Plants to Six US Cities

No.	Origin	Destination	Kansas Highway Mileage (Miles)																	Outside Kansas Highway Mileage (Miles)	Total Route Length (Miles)
			Southwest Area									Other Areas							Kansas State Total		
			East/West Highway					South/North Highway			South-west Total	East/West Highway		South/North Highway					Other Total			
			US 50	US 54	US 56	US 160	US 400	US 83	US 183	US 283		US 54	I 70	I 35	US 83	US 183	I 235	US 283				
1	Excel	Atlanta	34.91		11.91		0.44		44.50		91.76		262.27			16.94			279.21	370.97	804.70	1175.67
2	Excel	Chicago	34.91		11.91		0.44		44.50		91.76		259.45			16.94			276.39	368.15	530.59	898.74
3	Excel	Dallas		68.35	0.99	6.58				56.39	132.31								0	132.31	326.56	458.87
4	Excel	Los Angeles		66.40	0.99					19.22	86.61								0	86.61	1205.89	1292.50
5	Excel	New York	34.91		11.91		0.44		44.50		91.76		262.27			16.94			279.21	370.97	1252.21	1623.18
6	Excel	Phoenix			0.99					19.22	20.21								0	20.21	904.30	924.51
7	NB Dodge City	Atlanta	34.91		7.47				44.50		86.88		262.27			16.94			279.21	366.09	804.70	1170.79
8	NB Dodge City	Chicago	34.91		7.47				44.50		86.88		259.45			16.94			276.39	363.27	530.59	893.86
9	NB Dodge City	Dallas			3.44	6.58	0.44			56.39	66.85								0	66.85	394.91	461.76
10	NB Dodge City	Los Angeles	4.98							65.55	70.53		128.24					20.28	148.52	219.05	1194.14	1413.19
11	NB Dodge City	New York	34.91		7.74						42.65		259.45			16.94			276.39	319.04	1299.25	1618.29
12	NB Dodge City	Phoenix			0.99					19.22	20.21								0	20.21	907.20	927.41
13	NB Liberal	Atlanta						3.00			3.00								0	3.00	1175.86	1178.86
14	NB Liberal	Chicago		116.00							116.00	90.25		195.69			20.67		306.61	422.61	512.65	935.26
15	NB Liberal	Dallas						3.00			3.00								0	3.00	453.92	456.92
16	NB Liberal	Los Angeles						3.00			3.00								0	3.00	1209.72	1212.72
17	NB Liberal	New York		116.00							116.00	90.25		195.69			20.67		306.61	422.61	1235.47	1658.08
18	NB Liberal	Phoenix						3.00			3.00								0	3.00	841.73	844.73
19	Tyson	Atlanta	21.90					50.70			72.60		345.61		27.53				373.14	445.74	806.88	1252.62
20	Tyson	Chicago	21.90					50.70			72.60		345.61		27.53				373.14	445.74	529.95	975.69
21	Tyson	Dallas	71.40		3.44	6.58	0.44			56.39	138.25								0	138.25	402.82	541.07
22	Tyson	Los Angeles	43.97								43.97								0	43.97	1256.85	1300.82
23	Tyson	New York	21.90					50.70			72.60		345.61		27.53				373.14	445.74	1254.38	1700.12
24	Tyson	Phoenix	43.97								43.97								0	43.97	879.89	923.86
	Total		439.48	366.75	69.25	19.74	2.20	164.10	222.50	292.38	1576.40	180.50	2730.23	391.38	82.59	101.64	41.34	20.28	3547.96	5124.36	20715.36	25839.52

Note: NB: National Beef Pacing Co. LLC

APPENDIX VI: PRODUCER PRICE INDEX DETAILED DATA (1981-2007) (USDL 2007)

Table VI.1 PPI Data for Materials and Components for Construction (1981-2007)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	%change
1981	95.1	95.4	96.2	98.1	98.2	98.6	98.9	99	98.7	98.8	98.8	99.1	97.9	0
1982	99.4	99.8	99.9	100.1	100	100.3	100.2	99.9	100.2	100	99.9	100.3	100	2.15%
1983	101	101.7	102	102.4	102.6	102.9	103.1	103.4	103.2	103.4	103.5	103.8	102.8	2.8%
1984	104	104.8	105.4	105.7	105.5	105.6	105.9	106.2	106.1	106.2	106.1	106.4	105.6	2.72%
1985	106.7	106.7	106.7	106.9	107.6	108	107.9	107.8	107.4	107.4	107.2	107.5	107.3	1.61%
1986	107.7	107.8	107.9	108.4	108.4	108.2	108.2	108.1	108.1	108	108.1	107.9	108.1	0.75%
1987	108	108.2	108.5	108.7	108.9	109.3	109.8	110.2	110.7	111.2	111.9	112.4	109.8	1.57%
1988	113.6	113.8	114.4	115	115.4	115.8	116.5	116.7	117.1	117.5	118.1	118.7	116.1	5.74%
1989	119.4	119.9	120.5	121.1	121.5	121.5	121.6	121.6	121.9	122.3	122.1	121.7	121.3	4.48%
1990	121.8	121.9	122.5	123	123.2	122.8	123	123	123.3	123.4	123.4	123.5	122.9	1.32%
1991	124	123.9	124	124.3	124.5	125.2	125.3	124.7	124.7	124.5	124.4	124.5	124.5	1.30%
1992	124.9	125.9	126.6	126.8	126.8	126.5	126.3	126.4	126.8	126.7	126.9	127.8	126.5	1.61%
1993	129.1	130.9	132.5	132.8	132	131.3	131.1	131.6	132.3	132.5	133.3	134.2	132	4.35%
1994	135	135.1	135.5	135.1	135.3	136.2	136.3	136.8	137.5	138	139.1	139.4	136.6	3.48%
1995	140.5	141	141.7	142.2	142.2	142	142.6	142.9	143.1	142.7	142.3	142.1	142.1	4.03%
1996	141.9	142	142.2	142.5	143.5	144	143.7	144.1	144.8	144.3	144.9	144.7	143.6	1.06%
1997	145	145.7	146.2	146.8	147.2	147	147.2	147.1	146.8	146.4	146.6	146.4	146.5	2.02%
1998	146.3	146.4	146.7	147	146.9	146.7	147.2	147.4	147.3	146.7	146.6	146.6	146.8	0.20%
1999	146.9	147.3	147.8	148	148.5	149.5	150.5	150.4	149.6	149.1	149.4	149.8	148.9	1.43%
2000	150.4	150.8	151.3	151.6	151	151.2	150.8	150.4	150.3	150.2	150.1	149.9	150.7	1.21%
2001	149.7	150.1	150.2	150.4	151.6	151.7	151.1	151.1	150.9	150.3	150.2	149.9	150.6	0.07%
2002	150.2	150.2	150.7	151.1	151.4	151.5	151.7	152.1	152.1	151.7	151.2	151.1	151.3	0.46%
2003	151.4	152.1	152.3	152.9	152.9	153	153.6	153.7	155	155.2	155.6	155.6	153.6	1.52%
2004	156.2	159	161.9	164.7	166.9	166.9	167.5	169.8	170.9	170.8	170.7	171.3	166.4	8.33%
2005	173.1	174.7	175.1	175.4	175	175.5	175.7	175.4	177	179.2	180.8	181.7	176.6	6.13%
2006	184.2	185	185.5	186.7	188.2	189.2	190.2	190.7	191	190.4	189.6	189.6	188.4	6.68%
2007	190.3	190.6	191.2	192.1	192.8	193.5(P)	193.8(P)	193.6(P)	193.3(P)					
Average Annual % of change														2.68%

P : Preliminary. All indexes are subject to revision four months after original publication.
Item: materials and components for construction.
Base data: 8200

Table VI.2 PPI Data for Construction Machinery and Equipment (1981-2007)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	%change
1981	88.9	90.1	90.9	92.2	92.6	93.1	94.2	94.5	94.9	95.5	95.9	96.5	93.3	0.00%
1982	98	98.3	98.6	99.3	99.9	100	100.6	100.8	101.1	101.1	101.2	101.2	100	7.18%
1983	101.3	101.6	101.7	102	102.4	102.5	102.6	102.6	102.8	102.8	102.9	102.8	102.3	2.30%
1984	103	103.5	103.3	104	104	104.1	104.2	103.8	103.9	104	104	104	103.8	1.47%
1985	105.3	105.6	105.4	105.2	105.2	105.3	105.3	105.4	105.5	105.6	105.7	105.7	105.4	1.54%
1986	106.2	106.3	106.3	106.4	106.5	106.7	106.7	106.7	106.7	106.7	107.5	107.5	106.7	1.23%
1987	107.7	107.9	108.4	108.5	109.2	109.2	109.1	109.2	109.3	109.4	109.5	109.7	108.9	2.06%
1988	110.6	111	111	111.1	111.1	111.2	111.9	112.3	112.3	112.3	113	113.2	111.8	2.66%
1989	115.1	115.3	115.8	116.1	116.3	117.6	117.9	118.2	118.3	118.2	118.5	118.6	117.2	4.83%
1990	119.7	120.5	120.5	120.5	120.8	121.3	122.4	122.7	122.5	122.6	122.8	123.1	121.6	3.75%
1991	123.7	124.2	124.4	124.5	124.6	124.7	125.7	125.8	125.8	125.8	126.3	126.6	125.2	2.96%
1992	126.8	127.3	127.4	127.7	127.7	128.2	129.4	129.6	129.7	129.8	130.2	130.5	128.7	2.80%
1993	131.6	132.3	132.3	132	132.1	132.2	132.2	132.3	131.4	131.7	131.9	132	132	2.56%
1994	133.4	133.4	133.3	133.4	133.5	133.3	133.6	133.6	133.8	134.1	134.3	134.6	133.7	1.29%
1995	135.6	136	136.1	136.2	136.6	136.6	136.7	136.7	137.1	137.3	137.3	137.9	136.7	2.24%
1996	138.8	139.4	139.4	139.5	139.7	139.9	140	140.1	140.1	140.3	140.5	140.4	139.8	2.27%
1997	142	142	141.9	142	142	142	142	142.1	142.2	142.7	143	143.1	142.2	1.72%
1998	144.8	144.9	145	145	145.2	145.3	145.3	145.4	145.3	145.2	145.3	145.5	145.2	2.11%
1999	146.2	146.6	146.6	147.3	147.3	147.3	147.4	147.4	147.4	147.7	147.6	147.6	147.2	1.38%
2000	148.2	148.3	148.3	148.6	148.5	148.6	148.7	148.8	148.9	148.9	148.9	148.9	148.6	0.95%
2001	149	148.9	149	149.1	149.1	149.1	149.1	149.1	149.1	149.3	149.3	148.8	149.1	0.34%
2002	149.1	149.2	151.2	151.4	151.3	151.3	151.4	151.4	151.5	151.5	151.7	151.7	151.1	1.34%
2003	152.6	152.8	152.8	153.3	153.4	153.5	153.3	153.4	153.4	153.4	153.5	153.6	153.2	1.39%
2004	155	155.5	155.7	156.7	156.7	157.1	158.6	159.1	159.4	162.4	162.7	162.8	158.5	3.46%
2005	164.5	164.6	165.4	166	169	169.1	169.6	170	169.9	170.1	170.4	170.7	168.3	6.18%
2006	173	174.4	175.1	175	175.3	175.6	175.5	175.5	176.1	176.3	176.7	176.8	175.4	4.22%
2007	178.4	178.8	178.8	178.9	179.1	179.5(P)	179.9(P)	180.0(P)	179.8(P)					
Average Annual % of change														2.62%

P: Preliminary. All indexes are subject to revision four months after original publication.
Item: construction machinery and equipment
Base data: 8200