Methodology to Measure the Benefits and Costs of Rural Road Closure: A Kansas Case Study

by Michael W. Babcock and Abhinav Alakshendra

While rural roads are essential to state economies, increasing farm size and the corresponding increase in farm vehicle size coupled with declining rural population have stressed the rural road system. As county population declines the financial ability of counties to maintain and rebuild the road and bridge system isn't keeping up with the rate of deterioration. If counties can't maintain the rural road system as it currently exists, reducing the size of the system should be considered.

The overall objective of the paper is to estimate the economic impact on selected county road systems from reducing the size of the system. The specific objectives include (a) for a sample of three Kansas counties, measure the benefits and costs of keeping the road system as it currently exists and (b) for the same sample of Kansas counties, measure the benefits and costs of several scenarios of county road closure.

The main conclusion is that rural counties will be able to save money by closing some relatively low traffic volume roads and redirecting the savings toward increasing the quality of other county roads. Counties with relatively extensive road systems (miles of road per square mile) and relatively high population density are less likely to realize savings from road closure. In contrast, counties with less extensive road systems and relatively low population density are more likely to realize significant savings from closure of relatively low volume roads.

INTRODUCTION

Rural roads are an essential component of the U.S. transportation system. Though rural roads exist in every state, they are especially important to the economies of the northern and southern plains states. Table 1 includes 2008 public road length for the top dozen states in terms of the percent of U.S. total rural road miles. As indicated in Table 1 these dozen states account for nearly 44% of U.S. rural road miles. The table also contains the percent of each state's total road length that are rural roads. These range from a low of 69.5% (Texas) to a high of 97.8% (North Dakota) with an average of 83.7% for the 12 states as a group.

In general, rural roads are owned and administered by counties and townships. Table 2 contains 2008 public road miles owned by counties and townships in the same dozen states as in Table 1. The data in Table 2 indicate that the county plus township miles as a percent of state total miles averages 86.1% for the dozen states and 76% for the U.S. as a whole.

Table 3 displays 2008 rural vehicle miles as a percent of state total vehicle miles for the dozen states. In nine of the 12 states, rural roads account for at least 42% of the state's total vehicle miles. The corresponding percent for the U.S. as a whole was 33%.

The rural road system is important to the agricultural economies of the dozen states since the states with the largest rural road miles also account for a large percentage of U.S. crop production. Table 4 displays the 2010 combined production of corn, wheat, soybeans, and sorghum for the dozen states. Nearly 72% of the combined production of these four crops is produced in these states.

While rural roads are essential to state economies, increasing farm size and the corresponding increase in farm vehicle size coupled with declining rural population have stressed the rural road system.

Table 1: 2008 Public Road Length, Top Dozen States (Miles)

State	Rural	Urban	Rural Percent of U.S. or State Total	Rural Percent of U.S. Total
Texas	212,999	93,405	69.5%	7.2%
Kansas	127,859	12,750	90.9%	4.3%
Minnesota	117,613	20,626	85.1%	4.0%
Missouri	106,765	22,952	82.3%	3.6%
Iowa	102,919	11,307	90.1%	3.5%
Illinois	98,202	41,290	70.4%	3.3%
Oklahoma	97,268	16,057	85.8%	3.3%
Wisconsin	92,572	22,271	80.6%	3.1%
Arkansas	87,627	12,185	87.8%	2.9%
Michigan	85,853	35,813	70.6%	2.9%
Nebraska	87,297	6,318	93.3%	2.9%
North Dakota	84,945	1,897	97.8%	2.9%
Total - Top Dozen States			83.7% (Ave)	43.9%
U.S. Total	2,977,228	1,065,540	73.6%	-

Source: U.S. Department of Transportation, Federal Highway Administration.
State Statistical Abstracts 2008. http://www.fhwa.dot.gov/policyinformation/statistics/abstracts

When the county road grid was established in the U.S., each road was used by a large number of households and farms operating small vehicles. Today, each road is used by a small number of households and farms operating large vehicles. The typical vehicle types include automobiles, pickup trucks, farmer-owned tandem axle and semi-trucks, farm combines, and farm tractors pulling various types of farm equipment. Other vehicle types include commercial trucks, garbage trucks, and school buses.

In many counties the road and bridge characteristics are not sufficient to handle the stresses of the large vehicles. These characteristics include (1) narrow lanes that create safety problems, (2) overweight vehicles that break up road surfaces, (3) lack of hard surfaces that create rideability problems, and (4) road widths and design characteristics that are inadequate for large farm equipment and heavy trucks.

It is well known that U.S. agriculture has consolidated into fewer, larger farms due to economies of scale from larger farming operations. The increased size of farms has been accompanied by increasing farm vehicle size as well. Tractor and combine weight and width has increased and the great majority of farmers deliver their grain in semi-trucks.[1] Tandem axle trucks are used to deliver farm supplies. Declining rural population has caused school districts to use larger buses to transport fewer children over longer distances to consolidated schools. The road width and design characteristics of rural roads and bridges are inadequate for the larger and heavier vehicles that are using them.[2]

As county population declines, the financial ability of counties to maintain and rebuild the road and bridge system isn't keeping up with the rate of deterioration. Many rural counties don't have the funds to maintain the existing system with the heavier vehicles that are using the system. Current economic conditions have resulted in most states reducing their budgets. Thus, increased state aid for rural road maintenance is unlikely to occur.

Table 2: 2008 Public Road Length Owned by Counties and Townships, Top Dozen States (Miles)

State	County	Percent of State Total	Township	Percent of State Total	County & Township Percent of U.S. or State Total
Texas	145,632	47.5%	79,729	26.0%	73.5%
Kansas	113,338	80.6%	15,725	11.2%	91.8%
Minnesota	44,876	32.5%	77,397	56.0%	88.5%
Missouri	73,024	56.3%	21,684	16.7%	73.0%
Iowa	89,564	78.4%	15,095	13.2%	91.6%
Illinois	16,367	11.7%	106,130	76.1%	87.8%
Oklahoma	80,079	70.7%	19,706	17.4%	88.1%
Wisconsin	20,717	18.0%	81,449	70.9%	88.9%
Arkansas	66,139	66.3%	14,575	14.6%	80.9%
Michigan	89,306	73.4%	21,108	17.3%	90.7%
Nebraska	60,949	65.1%	22,227	23.7%	88.8%
North Dakota	10,067	11.6%	67,825	78.1%	89.7%
Average, Top 12 States		51.0%		35.1%	86.1%
U.S. Total	1,788,046	44.2%	1,286,446	31.8%	76.0%

Source: U.S. Department of Transportation, Federal Highway Administration. *State Statistical Abstracts 2008*. http://www.fhwa.dot.gov/policyinformation/statistics/abstracts

The purpose of this paper is to present a methodology that county road supervisors and county engineers can use to evaluate rural road investment or disinvestment proposals and to provide information to state DOTs and legislators in developing rural road policies. The methodology will be illustrated using data from a recently completed Kansas study (Babcock and Alakshendra 2011).

LITERATURE REVIEW

There is a large literature on various aspects of low volume roads, and this review is not a comprehensive discussion of that literature. Instead, only the previous studies that are most closely related to this study are discussed.

The objective of the Tolliver et al. (2011) study was to quantify the investment and maintenance needs of the county and local roads that serve as agricultural logistics routes in North Dakota. To accomplish the objectives they developed an integrated system of models to predict crop production, truck movements, and roadway investment and maintenance needs for individual road segments. Their model predicts flows from 1,406 crop-producing zones to 317 elevators and plants and forecasts improvements and maintenance costs for paved and unpaved roads.

The authors found that the estimated resurfacing costs per mile of major agricultural distribution routes is 40% greater than the estimated resurfacing cost per mile on non-agricultural routes. They also discovered the average annual cost to resurface and maintain paved agricultural roads is $18,300 per mile. Other findings include:

Table 3: 2008 Rural Vehicle Miles Traveled as a Percent of State Total Vehicle Miles, Top Dozen States

State	Rural Percent of U.S. or State Total
Texas	30.0%
Kansas	48.7%
Minnesota	43.9%
Missouri	41.8%
Iowa	60.3%
Illinois	25.7%
Oklahoma	48.0%
Wisconsin	46.9%
Arkansas	59.5%
Michigan	31.3%
Nebraska	56.9%
North Dakota	71.8%
U.S. Total	33.3%

Source: U.S. Department of Transportation, Federal Highway Administration. *State Statistical Abstracts 2008*. http://www.fhwa.dot.gov/policyinformation/statistics/abstracts

Table 4: 2010 Combined Production of Corn, Wheat, Soybeans, and Sorghum in Central Plains States (Millions of Bushels)

State	Bushels	Percent of U.S. Total
Texas	553.7	3.0%
Kansas	1,250.4	6.8%
Minnesota	1,709.2	9.3%
Missouri	594.6	3.2%
Iowa	2,650.0	14.5%
Illinois	2,432.6	13.3%
Oklahoma	190.0	1.0%
Wisconsin	599.2	3.3%
Arkansas	178.1	1.0%
Michigan	439.4	2.4%
Nebraska	1,807.8	9.9%
North Dakota	748.2	4.1%
U.S. Total	18,330.0	71.8%

Source: U.S. Department of Agriculture, National Agricultural Statistics Service: http://www.usda.nass.gov.

1. The average annual cost to maintain gravel surface agricultural roads ranges from approximately $3,900 per mile for roads with the lowest traffic levels to roughly $6,600 per mile for roads with 150 to 200 ADT.
2. The estimated cost to maintain 20-year pavement life cycles and acceptable levels of service on county and local roads in North Dakota is roughly double the historical funding level.

Jahren et al. (2005) conducted a study of Minnesota rural roads for the Minnesota Department of Transportation (DOT). The objective of the study was to identify the methods and costs of maintaining and upgrading a gravel road. The research involved three parts with the first one being a historical analysis based on the spending history for low-volume roads in the annual reports of a sample of Minnesota counties. The second part is development of a method for estimating the cost of maintaining gravel roads. The final part of the study is the development of an economic analysis example that can be used for making specific road investment decisions.

The authors concluded that the historical costs to maintain both gravel and bituminous roads were between $1,500 and $2,500 per mile. The authors concluded that maintenance cost savings alone can't justify the investment in a hot mix asphalt upgrade.

The South Dakota DOT sponsored a study conducted by Applied Pavement Technology Inc. (2004). The objective of the study was to create a process that allows the user to compare the costs associated with different types of roads in order to provide assistance in deciding which surface type, hot-mix asphalt (HMA), blotter, gravel or stabilized gravel, is most economical under a certain set of circumstances.

To achieve the objectives, the authors used life-cycle cost analysis (LCCA) that focuses on selecting the most cost effective road surface to meet a specific need. The results of the LCCA for each road section were combined for use in model development to determine whether statistically significant relationships existed between variables, including surface type, ADT, terrain type, subgrade type, and truck traffic. The final results showed that ADT is statistically significant in calculating agency and vehicle operating costs on HMA, blotter, and gravel roads.

Jerry Anderson and John Sessions (1991) used mixed integer linear programming (MIP) to analyze the intermittent road management problem in *Managing Low-Volume Road Systems Intermittent Use*, published as Transportation Research Record 1291. The paper is written in the context of timber harvesting regions. The objective is to minimize the discounted value of transportation costs, road opening costs, road closing costs, and road maintenance costs. The authors compute the minimum value of simultaneous consideration of all four costs in the objective function. The solution also indicates the open road segments in the network that minimizes costs. Next, they compute the total costs and open road segments if opening and closing costs are not considered simultaneously with transport and road maintenance costs. The total costs are 13% higher than the optimal solution that considers all four costs simultaneously.

C. Phillip Baumet et al. (1986) estimated the benefits of keeping groups of existing roads in the county road system. The authors selected three cases study areas in Iowa. They discovered that in areas with a large non-farm population, only a small number of roads can be abandoned without increasing vehicle travel cost more than the savings from eliminating them. They also found that in areas with a relatively small rural population and a large percent of gravel roads, only a small number of roads with no property access can be abandoned before the additional travel costs exceed the cost savings from eliminating the roads from the system. The authors discovered that in areas with a small rural population and a high percent of paved roads, a relatively large number of miles of county roads with no property access can be abandoned, and the savings from abandoning the roads will exceed the additional travel costs.

Steven D. Hanson et al. (1985) describe the variable costs of the predominant types of vehicles operating on Iowa rural county roads. The authors found that cost per mile is lowest on paved surfaces for all vehicles. For automobiles, pickup trucks, and commercial vans, the cost per mile increases 38% to 40% on gravel surfaces and 77% to 80% on earth surfaces. The costs per mile for farmer-owned tandem trucks increases 42% to 45% on gravel, and 84% to 91% on earth surfaces. Both farmer-owned and commercial semi trailer costs rose 50% on gravel and 100% on earth surfaces relative to the costs of paved surfaces.

Peter S. Helmberger et al. (1990) develop a method to assess the economic impact of a rural road management study. The strategy considers rural road abandonment and/or improvement, and it is employed in a case study of a Minnesota county. The management scenarios used in the study include the following:

1. The baseline scenario simulates traffic flows prior to any change in strategy, using data obtained from a survey. The scenario develops travel and maintenance costs to examine changes in these costs of various scenarios.
2. Minimum Mileage System. This scenario eliminates all road links that are dead ends.
3. All Paved System. This scenario upgrades the road network and brings all bridges in the system up to acceptable standards.
4. Improve and Remove. This scenario is a combination of rural road and bridge improvements and closures.

A scenario that reduces county road mileage with no adverse effect on travel costs resulted in total costs of $98,373, or $24,433 below the baseline costs. Thus the study demonstrated that net benefits can be increased by reducing the mileage of the county road system.

A report by the Kentucky Transportation Center examines the question of when to pave a gravel road. The authors calculate an example comparing the maintenance costs per mile of paved and gravel roads and conclude that gravel roads have lower maintenance and construction costs. However, the report points out that vehicle costs for the road user are two to three times higher for a gravel road compared to a paved road. Passenger car user costs are 40% higher on a gravel road than a paved road. Thus, when user costs are considered, paving the roadway may minimize the combined county costs and user costs.

Peter E. Sebaaly et al. (2003) evaluate the impact of agricultural equipment on the actual response of low-volume roads in South Dakota. To accomplish this objective, one gravel section and one blotter section were instrumented in South Dakota and tested under various amounts of agricultural equipment use.

The authors concluded that the impacts of agricultural equipment on low-volume roads depends on factors such as season, load level, thickness of crushed aggregate base (CAB), and soil type. They said damage can be reduced with a thicker CAB or by subjecting the agricultural equipment to the legal load limit, i.e. about 20,000 lb.

In “Modeling the Rationalization of Rural Road Networks: The Case of Saskatchewan,” Paul Christensen, James Nolan, and Gordon Sparks develop a mathematical model of rural road investment/abandonment based upon traffic flows and the cost of maintaining a given road surface type. The authors note that by incorporating demand, maintenance costs, and routing decisions they can develop a systematic approach to the problem of rural road abandonment and make planning decisions easier and more politically justifiable.

The authors use a network model that contains a set of road decisions (M) where the set M includes (1) the status quo, (2) abandonment, and (3) upgrade of road surface. The network configurations examined by the authors involved a considerable amount of road abandonment and rerouting of users. They found that the scenario with an unconstrained capital budget resulted in the most convenient network for users. They indicated that the future of the rural road network in Saskatchewan will involve a tradeoff between cost and convenience.

The contribution of our paper to the literature in this area is two-fold. First, it is the only road rationalization paper that focuses on how to do such a study. The network model employed in the study (TransCAD) is more technically advanced than models used in previous studies.

PROCEDURES

Measurement of the benefits and costs of retaining all the rural roads in a county as opposed to closure of selected links requires the following eight step procedure, developed by the authors, which is illustrated with Kansas data (Babcock and Alakshendra 2011).

1. Establish objectives.
2. Select study areas (counties).
3. Identify rural residents in the selected study areas.
4. Identify managers of grain elevators and road supervisors of study areas.
5. Design questionnaires for rural residents, grain elevator managers, and study area road supervisors.
6. Conduct a survey of road supervisors and grain elevator managers in the study area.
7. Calibrate the network model (TransCAD).
8. Calculate benefit-cost ratios of closing selected road segments in the study areas' road system rather than retaining them.

Any study must start with clear objectives to provide a framework for the research effort. In this type of study, the objectives are determined by the information needed by the sponsoring agency, usually the state DOT. In a study recently completed for the state of Kansas, the following objectives were established by the Kansas Department of Transportation (KDOT).

The overall objective of the research is to estimate the economic impact on selected county road systems from reducing the size of the system. The specific objectives include:

1. For a sample of three Kansas counties, measure the benefits and costs of keeping the road system as it currently exists.
2. For the same sample of Kansas counties, measure the benefits and costs of several scenarios of county road closure.

Study-area counties that vary significantly in socio-economic characteristics should be selected in order to achieve the objectives of the study. These characteristics include location, geographic size, population density, population characteristics (age, sex, race), per capita income, unemployment rates, and industry mix. Also, since the study is concerned with rural roads, the selected counties should have large crop production.

The counties selected for analysis in the Kansas study were Brown (northeast), Pratt (south-central), and Thomas (northwest). The populations of the selected counties are similar (between 7,300 and 9,900 in 2009), but they vary greatly in size and population density (2009-2010 Governor's Economic and Demographic Report, Appendix F). Brown County has 571 square miles and 19 people per square mile while Thomas County has 1,075 square miles and only eight people per square mile. The distribution of population within the counties varies substantially. In Pratt County, the city of Pratt (the county seat) accounts for nearly 68% of the total county population while Hiawatha (county seat of Brown County) represents only 31% of the county population (2009-2010 Governor's Economic and Demographic Report, Appendix F).

Local government was the largest employer in all three counties but ranged from a low of 14.3% of total county employment (Pratt County) to a high of 23.8% (Brown County) (U.S. Department of Commerce). The industry employment distribution of the counties also varied. Large employers in one county but not the others were manufacturing (9.2% of Brown County employment) and accommodations and food service (10.3% of Thomas County employment) (U.S. Department of Commerce).

In 2008, per capita income ranged from a high in Pratt County of $38,638 to a low of $35,019 (Brown County) (U.S. Census Bureau). Median personal income varied from a high of $45,735 (Thomas County) to a low of $38,162 (Brown County) (U.S. Census Bureau).

All three counties have large agricultural production. In Brown County, the 2007-2009 average total production of corn, wheat, sorghum, and soybeans was 21.5 million bushels with corn accounting for 75% and soybeans 23% of the total (Kansas Department of Agriculture). The 2007-

2009 average total production for the same four crops in Pratt County was 18.7 million bushels with corn accounting for 55% of the total production and wheat representing 30% (Kansas Department of Agriculture). The corresponding figure for Thomas County was 30.8 million bushels with corn and wheat accounting for 63% and 25% of total production (Kansas Department of Agriculture).

After the counties are selected, the third step is identification of the rural residents in each county. This can be done by obtaining a directory of the county with each resident's mailing address. In the Kansas study, the mailing addresses for the rural residents of Pratt and Thomas County were obtained from Farm & Home Publishers for Pratt County and Central Publishing Inc. for Thomas County. These directories have the name, mailing address, township, and phone number of each county resident. In Brown County, the questionnaires were distributed to rural residents by township representatives.

In addition to the travel data of rural residents, the study requires motor carrier inbound grain and outbound fertilizer shipments of grain elevators. The names of grain elevator managers along with mailing addresses and phone numbers are usually found in a directory published by the state grain and feed association. In the Kansas study, this information is available in the *2010 Kansas Official Directory* published by the Kansas Grain and Feed Association.

Brown County crops are stored and marketed by Ag Partners Coop, Fairview Mills, Morrill Elevator Inc, and Farmers Coop Elevator (Sabetha). These four grain companies collectively operate 10 grain elevators with a total storage capacity of 9.6 million bushels (Kansas Grain and Feed Association, *2010 Official Kansas Directory*).

The elevator system in Pratt County includes ADM Grain, Cairo Coop Exchange, Kanza Coop Association, and Farmers Coop Equity Exchange. These four grain companies collectively operate 23 grain elevators with total storage capacity of 20.2 million bushels (Kansas Grain and Feed Association, *2010 Kansas Official Directory*).

Thomas County agriculture is served by ADM Grain, Frontier Ag Inc, Bartlett Grain, Cooper Grain, Cornerstone Ag LLC, and Hi Plains Coop Assn. These six grain companies collectively operate 39 grain elevators with total storage capacity of 49.4 million bushels, although not all of the elevators operated by these grain companies are located in Thomas County (Kansas Grain and Feed Association, *2010 Kansas Official Directory*).

Contact information for county road supervisors can be easily obtained from the county website.

SURVEY DESIGN

Step 5 is to design questionnaires to be distributed to residents of the sample counties, grain elevator managers, and county road supervisors to obtain the data to estimate the network model. In the Kansas study, the rural resident transportation questionnaire has three parts: Transportation Equipment, Outbound Trips, and Inbound Trips. The first part asks the respondents what types and amounts of farm equipment, trucks, and automobiles are owned by members of the household. The second part of the rural resident questionnaire requests information on the following:

- Number of tractor, combine, and grain wagon trips on the county roads
- Number of miles of county roads used to make tractor and combine trips
- Number of times the county roads are used to make auto, pickup truck, single axle truck, tandem axle truck, semi truck, and grain wagon trips
- Destinations and number of trips by auto, pickup truck, single axle truck, tandem axle truck, and semi truck

The last part of the rural resident survey asks the respondents how many trips are made to their location in various types of vehicles. The residents are also asked to provide the origins of trips to their location by various types of vehicles.

Managers of grain elevator companies completed a questionnaire that has three parts: Grain Receipts, Market Area, and Fertilizer Delivery to Farms. The first part of the survey asks the grain company managers for their corn, wheat, sorghum, and soybean receipts for the 2007-2009 period and what percent of their total receipts were delivered to their elevator(s) by various types of trucks. In the next part of the survey, the respondents were asked the average distance from which farmers deliver their grain and the number of county road miles by surface type that farmers use to deliver grain to their elevator(s). The last part of the survey requests data for the percent of the grain company's fertilizer deliveries that were made in various types of trucks. Other information requested in the last part of the questionnaire includes the following:

- Number of miles by road surface type that were used to deliver fertilizer to farms
- The average distance (miles) that fertilizer is delivered to farms
- The number of trips made to deliver fertilizer to farms by season of the year

The county road supervisors for Brown, Pratt, and Thomas County each completed two questionnaires. One is titled County Road Supervisor's Survey and the other is County Maintenance, Construction, and Reconstruction Costs.

The County Road Supervisor's Survey has two parts, Current Condition of County Roads and Revenue and Expense. The first part of the questionnaire asks the road supervisors how many miles of road and bridges is the county responsible for (by surface type), and to rate the condition of the county's cement, asphalt, and unpaved roads. The second part of the survey requests the county's annual expenditure for road and bridge maintenance for the 2007-2009 period, and the sources of revenue for the county's road and bridge maintenance budget.

The County Maintenance, Construction, and Reconstruction Costs questionnaire has four parts as follows:

Part A - Maintenance
Part B - Construction/Reconstruction Costs
Part C - Types of Paved Road Treatments
Part D - Types of Gravel Road Treatments

In Part A, the county road supervisors were asked to provide a general description of maintenance activities in the county, including chip seals, overlays, and recycle. In Part B, the respondents were asked to give a general description of the construction/reconstruction activities for paved and gravel roads as well as bridges. They were also asked how often these activities occur as well as the cost per mile of paved and gravel roads and the cost per average county bridge. In Part C, the respondents were asked to give a general description of paved road treatments, including crack seal, seal coat, overlay, striping and marking, mill and overlay, and patching. They were also requested to provide a general description of gravel road treatments such as blading, re-gravel, reclaiming, reshape cross section, and routine annual maintenance in Part D.

In Pratt County, a large generator of truck traffic is Pratt County Feeders, LLC, one of the largest cattle feedlots in Kansas. There are five parts to the questionnaire, including the following:

Part A - Capacity and Production
Part B - Inbound Truck Shipments
Part C - Outbound Truck Shipments
Part D - Origins of Inbound Truck Shipments
Part E - Truck Shipments on the Pratt County Road System

In Part A, the respondent is asked to provide data on the number of cattle on feed in the 2007-2009 period, the number of bushels of feed grains delivered to the feedyard in the same period, the number of tons of distillers grain and feed supplements, and the amount of feeder cattle delivered to the feedyard. In Part B, the respondent is asked the percentage of various feed grains and supplements delivered to the feedyard in single axle truck, tandem axle truck, and semi-tractor trailer/trucks. In Part C of the questionnaire, the manager provided data on the percentage of total finished cattle and manure shipped from the feedyard in tandem axle trucks and semi-tractor trailer trucks. In Part D, the manager indicated the percentages of total inbound feed grains, distillers grain, feed supplements, and feeder cattle that originated at various distances from the feedyard. In

Part E, the Pratt Feeders manager was requested to provide the numbers of miles of paved and gravel Pratt County roads used by a typical inbound truck shipment of feed grains, distillers grain, feed supplements, and feeder cattle. The complete surveys are available upon request.

A total of 410 and 426 rural resident questionnaires were mailed to Pratt County and Thomas County residents, respectively. A total of 125 questionnaires were returned by the residents of each county, resulting in return rates of 30.5% (Pratt County) and 29.3% (Thomas County). However, a few of the returned questionnaires were only partially completed. Unlike Pratt and Thomas County, the Brown County road system is a township system whereby the county operates and maintains a system of designated county roads and each of the 10 townships operates and maintains the roads in the township designated as township roads. The questionnaires were distributed to township residents by township representatives. This resulted in only 120 questionnaires being distributed, but 55 were returned (46%).

The sixth step is to conduct the survey of grain elevator managers and county road supervisors, which begins with a phone call to them explaining the objectives of the study and how the research project could benefit the company and the county. During the call, surveyers explain the research objectives thoroughly, emphasize confidentiality, and ask for an appointment. At the interview, they explain the questionnaire in detail and answer all questions.

In the Kansas study, a member of the research team interviewed every grain elevator manager and county road supervisor in the three counties. At the interview, each of the county road supervisors provided detailed county road maps and annual reports for the 2006–2009 period. The annual reports contain county road mileage by type of surface as well as maintenance expenditures by type of road surface and number of road miles receiving maintenance expenditure during the year.

In the Kansas study, 10 of the 11 grain elevator managers that were interviewed returned the questionnaire and all the county road supervisors returned at least one or both of the two questionnaires.

CALIBRATE THE NETWORK MODEL

In order to evaluate the feasibility of road closure, a benefit-cost technique was used and applied to the three Kansas counties. The benefits of rural road closure are avoided costs to the county of keeping the roads in the system, including maintenance, reconstruction, and resurfacing costs. The costs are the additional travel costs of the traveling public due to closure of lightly traveled roads. If the measured benefits exceed the costs, the evaluated roads should be closed or remain in the county road system if the costs of simulated closure exceed the benefits.

One way to measure these benefits and costs is through use of a network model for each sample county. The model estimates the minimum travel cost routings of all the trips in the county. The network model routes each of the trip classes from the trip origin, through the county road system to the destination at minimum travel cost. Then the network model measures the travel cost without the designated road segments in the network. The difference in the total travel costs of the two scenarios is the travel cost impact of keeping the designated roads in the system as opposed to closing them.

The network model used in the Kansas study is TransCAD. TransCAD is a geographic information system software product produced by Caliper Corporation for transportation and public transport applications. In addition to the standard point, line, area, and image layers in a GIS map, TransCAD supports route system layers and has tools for creating, manipulating, and displaying routes. TransCAD uses a network data structure to support routing and network optimization models. TransCAD includes trip generation, distribution, mode choice, and traffic assignment that support transportation planning and travel demand forecasting. For more information about TransCAD see www.caliper.com.

Procedure Used in the Kansas Study

Before getting into the details of the benefits and costs it is useful to discuss the general procedures used in the Kansas study. TransCAD calculates the total travel cost for all rural resident trips assuming the county road network as it currently exists. Then selected low-volume road segments are removed from the network and TransCAD recalculates total travel cost for rural resident trips. The difference between the two travel cost simulations is the cost of the assumed closed roads. The benefit of road closure is the avoided maintenance and reconstruction costs of the closed road segments. Total benefit is calculated by multiplying the number of miles assumed to be closed by the avoided maintenance cost per mile.

In each county, 10 road segments were selected as potential candidates for simulated closure. Ten road segments were selected in order to analyze the traffic impacts on alternative roads in the local area of the closed road segment. Selection of the road segments was based on many factors, but the most important criterion was the traffic volume on these roads.

The identification of the 10 road segments and calculation of traffic rerouting as a result of simulated closure was a three-step process. In the first stage, relatively low volume roads were identified by KDOT traffic count data. Single access roads (the only road between a specific origin and destination) were eliminated as candidates for simulated closure. The second stage involved identification of roads whose traffic would be affected by closure of an area road segment. For example, it was assumed that by closing a road segment, in most cases, traffic on a parallel road would increase. In the third stage, TransCAD rerouted all the previous traffic on the closed road segment to determine the traffic impact on other roads after the candidate road is deleted from the network.

Based on rural resident survey destination information, level of use of county roads, types of vehicles used, and trip origins, an Origin-Destination (O&D) matrix can be obtained. To create the O&D matrix, origin and destination information was used along with the average number of daily trips. The most important variable in the O&D matrix is the travel cost which is the total cost to travel from the origin to the destination. The rural resident survey provided length of trip information. Thus, in order to determine travel cost, free flow speed (the posted speed limit) was used. TransCAD reroutes traffic after deleting the selected roads from the county network. The simulated closure of roads impacts the travel cost for some rural residents since traffic is directed to alternate roads. TransCAD then calculates the minimum travel cost for each of the 10 simulated road closures, which are summed to obtain total travel cost.

It was assumed that rural residents would use cars and pickup trucks for grocery and pleasure trips while five axle semis and tandem axle trucks are used for grain hauling. In the rural resident survey, respondents were asked to indicate their destination for each type of vehicle. However, to simplify computation, only the most importation destination for each vehicle type was used. Also to simplify computation, all truck types (other than pickup) were combined into one category. Thus, there are three vehicle types in the analysis: cars, pickups, and trucks.

CALCULATION OF BENEFITS AND COSTS OF SIMULATED ROAD CLOSURE

The final step in the model is the calculation of benefits and costs of simulated road closure. The model is demonstrated using data from Brown County of the Kansas study. Benefits and costs of Pratt and Thomas counties were calculated in the same manner as Brown County.

Table 5 lists all the links selected for simulated closure in Brown County and the length of each link that varies from a minimum of two miles to a maximum of 6.51 miles.

Table 5: Deleted Links in Brown County

Link	Miles
Link 1	3.37
Link 2	3.96
Link 3	2.04
Link 4	4
Link 5	4
Link 6	4.44
Link 7	3
Link 8	2
Link 9	4.95
Link 10	6.51
Total (Miles)	38.27

Among the three selected counties, Brown County has the most extensive road network in terms of the ratio of the number of miles of road to the total area of the county. For this reason, Brown County had the highest mileage of simulated closure of the three counties in the analysis. The majority of links selected for simulated closure are in the northwest and southwest parts of the county, as most of the rural resident survey data were concentrated in these parts of the county. Every road segment selected for simulated closure has a superior or equivalent quality alternate route. For example, if Link 1 is a gravel road then the alternate route is a paved or an equivalent gravel road.

When road links from the Brown County road system were deleted from the network, one of the major challenges was identification of the other roads that were affected by the simulated closure of the road link. Identification of alternate routes was essential because of the need to estimate the traffic flow on the alternate roads. First, the traffic flow (Average Daily Traffic, ADT) on the selected alternate route was calculated using TransCAD with all the existing roads in the network. After deletion of the link from the system, the traffic on the alternate routes was recalculated. This results in the traffic flow on the alternate routes before and after deletion of the road link. Table 6 presents the percentage change in the traffic flow on the alternative routes after the selected links are deleted from the Brown County road network.

The data in Table 6 indicate that traffic volume per day is high on some of the alternative routes. The reason is that these alternative routes have better roads than the deleted links and some of the alternate routes include a state highway. The percentage change in ADT is less than 10% for eight of the 10 alternate routes and seven of the 10 have less than 4% change in ADT. The percentage increase in ADT for alternative route 6 is 123.6%. The ADT on alternate routes 8 and 9 decreased slightly.

Table 6 illustrates the variation in the traffic on alternative routes when the selected links are deleted from the network. Also, the data in Table 6 is a good indicator of whether selected links should be deleted from the county road network in the first place. For example, after link 6 is deleted, alternative route 6 experiences a large surge in ADT. Similarly, alternative route 2 experiences nearly a 20% increase in ADT after link 2 is eliminated from the network. In these cases, the traffic diversion to the alternative route is high, and congestion on the road increases. Thus, links 2 and 6 should not be deleted from the Brown County road system. It was decided that a 15% change in the ADT on alternative routes after the link is deleted would be the threshold level to determine whether a link should be deleted or remain in the county road network.[3] If the change in ADT on the alternative route after the link is deleted is greater than 15%, then the link should remain in the county road system. This threshold level of ADT provides an extra level of analysis to supplement the cost-benefit analysis in deciding whether to delete the link from the county road system.

Table 6: Brown County Traffic Variation on the Alternate Routes (ADT)

	Traffic Range Before Deletion (ADT)	Traffic Range After Deletion (ADT)	ADT Percentage Change
Alternate 1	>100 & <200	>100 & <200	3.47
Alternate 2	>300 & <400	>300 & <400	19.06
Alternate 3	>100 & <200	>100 & <200	8.47
Alternate 4	>400	>400	3.12
Alternate 5	>300 & <400	>300 & <400	3.25
Alternate 6	>300 & <400	>400	123.58
Alternate 7	>400	>400	1.94
Alternate 8	>400	>400	-1.07
Alternate 9	>400	>400	-0.77
Alternate 10	>400	>400	2.95

ADT is Average Daily Traffic

Table 7 provides the ADT by vehicle type for the links considered for simulated closure. Links 8 and 9 carry larger traffic so they cannot be considered to be low-volume roads and thus should not be deleted from the road system. It was decided that links should remain in the county road system if the total ADT on the link is higher than 60.[4] This was the case for all three counties.

Table 7: Traffic on the Selected Links to be Deleted in Brown County

	Total ADT	Car ADT	Pickup ADT	Truck ADT
Link 1	60	14	24	22
Link 2	**51**	**15**	**19**	**17**
Link 3	58	24	19	15
Link 4	35	13	13	9
Link 5	53	20	19	14
Link 6	**34**	**13**	**12**	**9**
Link 7	34	10	13	44
Link 8	**184**	**98**	**57**	**59**
Link 9	**151**	**67**	**50**	**34**
Link 10	48	19	17	12

An examination of Table 7 reveals the number of pickup trucks is very close to the number of cars using the roads. This interesting trend may be occurring because rural residents are using their pickup trucks for dual purpose trips such as combining their shopping trips with farm trips. Also, the number of trucks on some links is high, which is unusual. A possible reason for this could be the high concentration of rural resident data in one half of the county. Also, the number of grain elevators is high in that part of Brown County where most of the survey data originates.

Benefit-Cost Ratios

The benefit of deleting a road segment is the avoided maintenance cost of these roads. The maintenance costs are large and recurring in nature. The academic literature provides a large range from \$3000 to \$6000 per mile for gravel roads each year.[5] Road maintenance data were obtained from county road supervisors of each county, and some variation was found between counties and between years. It was decided to use two estimates of annual maintenance expense of \$3000 and \$4000 per mile per year.

In calculating the benefits, links 2, 6, 8, and 9 were not considered in the calculation for reasons explained above. When maintenance costs per mile are valued at the very conservative figure of \$3000 per mile, the benefits are \$68,760 and rise to \$91,680 for maintenance cost per mile of \$4000[6]. The benefits for each link are in Table 8.

The cost of deleting a road segment from the network is the additional travel cost borne by the road users due to more circuitous routes to destinations. To calculate total costs, an estimate is needed of the additional miles traveled after the link is deleted. This information is in Table 9.

Table 8: Benefits From the Deletion of Selected Links From Brown County

Link	Miles	Benefits @ \$3000 per mile	Benefits @ \$4000 per mile
Link 1	3.37	\$10,110	\$13,480
Link 2	**0**	**0**	**0**
Link 3	2.04	6120	8160
Link 4	4	12000	16000
Link 5	4	12000	16000
Link 6	**0**	**0**	**0**
Link 7	3	9000	12000
Link 8	**0**	**0**	**0**
Link 9	**0**	**0**	**0**
Link 10	6.51	19530	26040
Total	**22.92**	**\$68,760**	**\$91,680**

Table 9 contains the additional miles traveled when a link is deleted from the road system. These calculations are performed by TransCAD. In these calculations, TransCAD calculates the shortest route from origin to destination. As indicated in Table 9, the additional miles traveled for links 2, 6, 8, and 9 are zero since these links are not subject to closure for reasons explained above.

Operating cost per vehicle per mile for each of the three vehicle types is needed to calculate the total cost of simulated road closure. The operating costs per mile of the three vehicle types is from the AASHTO (1993)[7]. For cars, the cost per mile for gravel roads is 76.5¢; for pickup trucks 92.3¢, and for trucks 159.7¢. The operating cost per mile for trucks is the average of the tandem truck and semi-trailer costs per mile on gravel roads. To obtain the total cost by vehicle type the following equation is used.

(1) Total Cost = ADT x Operating Cost Per Mile x 365 Days x Average Extra Miles Traveled / 100

Table 9: Extra Miles Traveled Due to Road Closure in Brown County

	Distance Traveled Before Link is Deleted	Distance Traveled After Link is Deleted	Extra Miles Traveled Due to Road Closure
Link 1	3.37	5.46	2.09
Link 2	0	0	0
Link 3	2.04	4	1.96
Link 4	4	6.02	2.02
Link 5	4	5.99	1.99
Link 6	0	0	0
Link 7	3	5	2
Link 8	0	0	0
Link 9	0	0	0
Link 10	6.51	8.6	2.09
Total	**22.92**	**35.07**	**12.15**

The results are in Table 10. The total annual cost of simulated closure of six Brown County links is $226,147. Thus the ratio of benefits to costs assuming $3000 per mile maintenance cost is 0.30 ($68,760 / $226,147) and 0.41 ($91,680 / $226,147) when $4000 per mile is assumed. Thus, road maintenance per mile would have to increase to about $9,900 in order for the benefits to equal the costs. The conclusion is that all of the simulated links should remain in the Brown County road system.

Table 10: Annual Cost of Operating Vehicles in Brown County After Simulated Road Closure

Vehicle Type	ADT	Operating Cost Per Mile	Number of Days	Average Extra Miles Traveled*	Total Cost
Cars	100	76.5¢	365	2.025	$56,543
Pickup Trucks	105	92.3¢	365	2.025	71,632
Trucks	83	159.7¢	365	2.025	97,972
Total Cost					$226,147

*The sum of extra miles traveled due to simulated closure for links 1, 3, 4, 5, 7, and 10 which is 12.15 (Table 24) divided by 6.

The benefits and costs of simulated road closure for Pratt and Thomas County were calculated in the same manner as Brown County. In Pratt County, one of the 10 links was eliminated from simulated closure since the ADT on the alternative route increased by more than 15% when the link was removed from the Pratt County road system.

If it is assumed that annual maintenance cost per mile is $3,000, the ratio of benefits to costs for Pratt County is 0.995 ($93,810 / $94,236). The costs exceed the benefits by only $426. If annual maintenance cost per mile is assumed to be $4,000, the benefit-cost ratio is 1.33 ($125,080 / $94,236). Thus, if the very conservative maintenance cost of $3,000 per mile is assumed, the benefits of road closure approximately equal the costs. However, if $4,000 per mile is assumed to be the annual maintenance costs, the benefits exceed the costs by $30,844 so all nine of the links considered for closure should be closed.

In Thomas County, one of the 10 links was eliminated as a candidate for closure since ADT on the alternative route exceeded the ADT threshold of 60 after the link was deleted from the Thomas County road system.

If the annual maintenance costs per mile are assumed to be $3000, the benefit-cost ratio for Thomas County is 1.82 ($84,300 / $46,385). If the annual maintenance cost per mile is $4000, the benefit-cost ratio is 2.42 ($112,400 / $46,385). The conclusion is that even with the very conservative maintenance figure of $3000 per mile the benefits of road closure significantly exceed the costs. Thus, nine of the 10 links in Thomas County should be closed.

CONCLUSION

The rural road system is under stress in many U.S. states. The increasing size of farms has led to increasing farm vehicle size as well. The road width and design characteristics of rural roads and bridges are inadequate for the larger and heavier vehicles that are using them. As county population declines the financial ability of counties to maintain and rebuild the road and bridge system isn't keeping up with the rate of deterioration. Many U.S. counties don't have the funds to maintain the existing road system due to the heavier vehicles that are using them. If the county road and bridge system can't be maintained as it is, reducing the size of the system should be considered. This paper suggested a methodology to evaluate the benefits and costs of reducing the county road network. The methodology is flexible and can accommodate any number of, or location of, links to be considered for closure as well as the size of study areas.

Benefit-cost analysis was used to examine the question of road closure in the three counties. The cost of road closure is the additional travel cost of rural residents due to more circuitous routing to their destinations. The benefit is the avoided maintenance costs of roads removed from the county network. Total annual costs are measured by the following equation:

Total Cost = ADT (on road segments considered for simulated closure) x Vehicle Operating Cost Per Mile x 365 days x Average Extra Miles Traveled / 100. Total benefit is calculated by multiplying the number of miles assumed to be closed by the avoided maintenance cost per mile.

In each county, 10 road segments were selected as potential candidates for simulated closure. Ten road segments were selected in order to analyze the traffic impacts on alternative roads in the local area of the closed road segment. Selection of the road segments was based on many factors, but the most important criterion was the traffic volume on these roads.

Table 11 contains the benefit-cost ratios for simulated closure of roads in the three counties. One set of ratios is calculated assuming annual maintenance cost per mile of $3000, and the other set assumes $4000 per mile. The benefit-cost ratios for Brown County are 0.30 and 0.41. Thus, none of the 10 road segments evaluated in Brown County should be closed. For Pratt County, the benefits of simulated road closure are approximately equal to the costs if maintenance cost of $3000 per mile is assumed, but if maintenance cost per mile is assumed to be $4000, the benefit-cost ratio is 1.33. The latter ratio indicates that Pratt County would save money by closing the evaluated road segments. The benefit-cost ratios for Thomas County are 1.82 and 2.42, indicating that all of the evaluated road segments should be closed.

Table 11: Benefit-Cost Ratios of the Three Counties

Benefit-Cost Ratios Assuming Annual Maintenance Cost of $3000 Per Mile			
County	**Benefits**	**Costs**	**Benefit-Cost Ratio**
Brown	$68,760	$226,147	0.30
Pratt	$93,810	$94,236	1.00
Thomas	$84,300	$46,385	1.82
Benefit-Cost Ratios Assuming Annual Maintenance Cost of $4000 Per Mile			
County	**Benefits**	**Costs**	**Benefit-Cost Ratio**
Brown	$91,680	$226,147	0.41
Pratt	$125,080	$94,236	1.33
Thomas	$112,400	$46,385	2.42

The main conclusion is that rural counties will be able to save money by closing some relatively low-volume roads and redirecting the saving toward increasing the quality of other county roads. Counties with relatively extensive road systems (miles of road per square mile) and relatively high population density (i.e., Brown County) are less likely to realize savings from road closure. In contrast, counties with less extensive road systems and relatively low population density (i.e., Thomas County) are more likely to realize significant savings from closure of relatively low-volume roads.

This study did not consider the benefits and costs of bridges on the road segments considered for closure since it was beyond the scope of the study. The benefits of including bridges include the avoided cost of maintaining and reconstructing bridges. The costs would be unaffected since the additional travel costs would be the same. Rural residents would simultaneously lose access to the road and any bridges on the road. Thus, the inclusion of bridges in the analysis would increase the benefits relative to the costs, increasing the benefit-cost ratio.

Road supervisors should consider some demonstration projects where the roads with minimal ADT are closed, but no single access roads should be considered for closure so rural residents continue to have access to the county road system.

Endnotes

1. According to KDOT (2009), a survey of 21 Kansas grain companies found that 68% of total 2007 corn and sorghum receipts were delivered by semi-tractor trailers. Tandem axle trucks were used to deliver 16% of the 2007 total corn and sorghum receipts of the 21 companies.

2. According to KDOT (2009), a survey of eight Kansas counties found that 77% of county roads were unpaved and the respondents rated 52% of the road miles in very poor to fair condition. The KDOT study (2005) indicated that 24% of the county bridges in Kansas were either structurally deficient or functionally obsolete.

3. The 15% threshold for ADT change on alternate routes was set relatively high to keep most of the links in the benefit-cost analysis. Only three of the 30 links (10%) in the three county analysis exceeded the 15% threshold.

4. Keeping the link in the county road system if total ADT on the link was greater than 60 was done in order to keep most of the links in the benefit-cost analysis. Only three or 10% of the 30 links in the analysis had ADT greater than 60.

5. Tolliver et al. (2011) estimated annual county gravel road maintenance cost per mile as $3,913 per mile for roads with 0-50 ADT and $4,213 per mile for those with 50-100 ADT. Jahren et al. (2005) estimated average annual maintenance cost per mile of gravel roads at $4,160. Since 77% of the 30 links in the analysis have ADT of 50 or less, the assumption of $3,000 and $4,000 per mile annual maintenance cost seemed reasonable.

6. When traffic is diverted to alternate routes by closure of a link, maintenance costs on the alternative route would increase by an insignificant amount because the ADT diverted is small. Also, the maintenance cost per mile used in this study is a countywide average. The maintenance cost of individual links is unknown.

7. The operating costs per mile were computed in the following manner. The current cost of the auto was determined to be 55 cents per mile on paved roads. Based on information in AASHTO (1993), the 55 cents per mile on paved roads was converted to 76.5 cents per mile on gravel roads. The operating cost per mile of pickup trucks and heavy trucks was computed using the ratios of the auto cost per mile on gravel roads to the cost per mile for the other two vehicle types based on information in AASHTO (1993).

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Michael W. Babcock *is full professor of economics at Kansas State University. In his 40-year career at KSU, he has published over 80 articles in professional journals, along with numerous monographs and technical reports. His research has been cited in over 75 books, the transportation press and professional journals. He has been principal investigator or co-principal investigator on 33 federal and state research grants worth a total of $2.3 million.*

Babcock has received numerous national awards for his transportation research. He has won five best paper awards from the Transportation Research Forum (TRF) for outstanding research in transportation economics. He has received the E.S. Bagley award five times from the economics Department of KSU for outstanding achievements in transportation economics research. In 1998, he was awarded the ISBR Senior Faculty Award for research excellence in The Social and Behavioral Sciences from KSU. In 2005, he received the Herbert O. Whitten TRF Service Award (the highest honor bestowed by TRF) for professional contributions to TRF. He has served as general editor of the Journal of the Transportation Research Forum since 2000.

Abhinav Alakshendra *is a Ph.D. candidate in economics at Kansas State University. His research interests are mainly concentrated in the fields of development economics, labor economics, and regional economics. His research uses an applied econometrics framework and is empirical in nature. He has been part of various research projects and recently co-authored a technical report for the Kansas Department of Transportation. He is also co-author of "Instructor's Resource Manual and Test Bank" for Economic Development published by Cambridge University Press.*