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The Economics of Reducing the County Road System: Three Case Studies in Iowa

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16. Abstract

This research project looked at the economic benefits and costs associated with alternative strategies for abandoning low volume rural highways and bridges. Three test counties in Iowa were studied; each 100 square miles in size: Hamilton County having a high agricultural tax base and a high percentage of paved roads and few bridges; Shelby County having a relatively low agricultural tax base, hilly terrain and a low percentage of paved roads and many bridges; and Linn County having a high agricultural tax base, high percentage of paved roads and a large number of non-farm households.

A questionnaire survey was undertaken to develop estimates of farm and household travel patterns. Benefits and costs were calculated associated with the abandonment of various segments of rural highway and bridge mileages in each county. "Benefits" calculated were reduced future reconstruction and maintenance costs, whereas "costs" were the added cost of travel resulting from the reduced highway mileage.

Some of the findings suggest limited cost savings from abandonment of county roads with no property access in areas with large non-farm rural population; relatively high cost savings from the abandonment of roads with no property access in areas with small rural population; the largest savings are likely from the conversion of public dead-end gravel roads with property or residence accesses to private drives.

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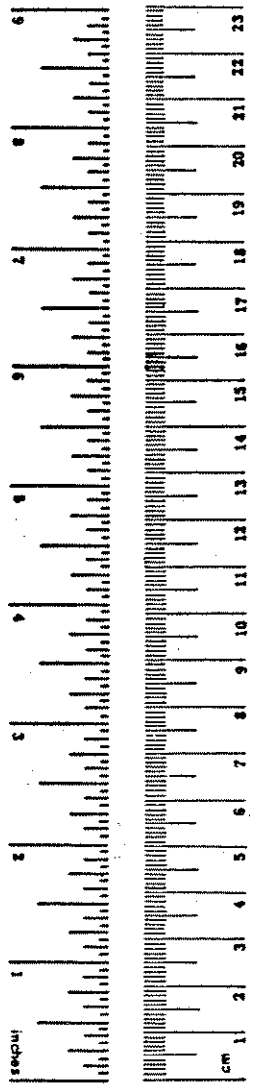
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
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cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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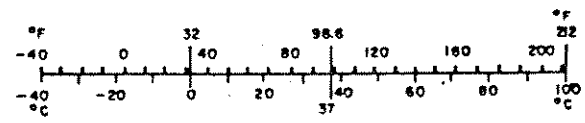

NOTICE

AVAILABILITY OF PROGRAM DISC

Anyone interested in obtaining a copy of the County Road Evaluation Program on disc, please send a check for $12.50 made out to **Iowa State University**, mail to:

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THE ECONOMICS OF REDUCING THE COUNTY ROAD SYSTEM: THREE CASE STUDIES IN IOWA

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In Cooperation With
The Highway Division and Planning and Research Division
Iowa Department of Transportation
and the
Iowa Highway Research Board
Iowa Department of Transportation Project HR242
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Mr. Jerry Nelson, County Engineer, Linn County, Iowa

Mr. Don Linnan, County Engineer, Buena Vista County, Iowa

Mr. Donald Sehr, County Supervisor, Johnson County, Iowa

Mr. Francis Forret, County Supervisor, Dallas County, Iowa

Mr. Rex Wiant, Iowa Department of Transportation, Ames, Iowa

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CHAPTER I

SUMMARY AND CONCLUSIONS

Many of today's local rural roads and bridges were built in the late 1800s and early 1900s, when overland transportation was limited to horse and wagon or the newly built railroad lines. Farms were small, and farmers needed road access to homes, schools, churches and markets. During the 1920s and 1930s, local rural roads were surfaced, mainly with gravel, and some bridges were replaced to carry six to seven ton loads. Since then, farm numbers have declined but farm size has increased, and the number of heavy vehicles traveling on these roads has increased. Farmers are using large tandem axle and semitrailer trucks as well as large farm tractor-wagon combinations; and large, heavy and wide combines travel on these roads from farms to fields and fields to farms. Farm supply and marketing firms are using large tandem axle and semitrailer trucks for their pickups and deliveries. At the same time that heavier vehicles are increasingly used on these roads, revenues to reconstruct and maintain the present system to accommodate the changing needs of rural America are declining in real terms.

This study estimated the benefits to the traveling public of keeping groups of existing roads in the system. These benefits were then compared to the costs of retaining these roads in the local rural road system. The basic purpose of the study is to develop guidelines for local supervisors and engineers in evaluating local rural road invest-

Dr. Tom Colvin and Dr. William Edwards of Iowa State University gave much help in developing the travel time penalty. Mr. Leroy Hamilton of the Iowa Department of Transportation supervised the origin and destination survey in Linn County. Mr. Mike Keefer and Mr. Bill Snow of the U.S. Post Office provided invaluable technical assistance in estimating the postal routes and costs. Mr. John Wallize edited the first draft of this report. Barbara Klett typed numerous progress reports and the early output of the study. Mrs. Roxanne Clemens cheerfully typed several versions of the final report manuscript.

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We extend our thanks to each of you!

ment or disinvestment proposals and to provide information to state legislatures in developing local rural road and bridge policies.

For this analysis, three case study areas of 100 square miles each were selected in Iowa. One study area, located in Hamilton County, has a relatively high agricultural tax base, a high percentage of paved roads, and relatively few bridges. The second study area, located in Shelby County, has a relatively low agricultural tax base, hilly terrain, a low percent of paved roads and a large number of bridges. The third study area, located in Linn County, has a relatively high agricultural tax base, a high percent of paved roads and a large number of non-farm households with commuters to Cedar Rapids and Waterloo.

A questionnaire was used to collect data from farm and non-farm residents in the three study areas. Data were obtained on the number of 1982 trips by origin, destination and type of vehicle.

A majority of the travel in the three study areas was for household purposes, including commuting to work, shopping and recreation. Almost 70 percent of the Linn County study area travel was for household purposes. Household travel in the Shelby and Hamilton County study areas represented 68 and 63 percent of total miles traveled. One-fourth of the Linn County study area travel miles was overhead traffic; overhead traffic travels through the area but does not originate and/or terminate in the area.

Farm travel, which includes all farm related traffic by automobiles, farm implements, farmer-owned trucks, and commercial vehicles which provide goods and services to farms, represented 30 and 35 per-

cent of total miles driven in the Shelby and Hamilton study areas, but only five percent of total miles driven in the Linn study area. In each study area, pickup truck miles were about three-fourths of total farm related traffic. Farm equipment and other farm truck travel each represented about 10 percent of total farm travel in the three study areas. Post office and school bus miles were about two percent of total miles in the Shelby and Hamilton study areas and only 0.6 percent of the total miles in the Linn study area. Thus, household and farm traffic are the major sources of travel on local rural roads.

While household traffic was a very large percent of total miles traveled, household travel represented a relatively small percent of total vehicle travel costs in the rural study areas. In the Shelby County study area, household travel represented 70 percent of total miles driven, but only 55 percent of travel costs. In the Hamilton County study area, household travel represented 63 percent of total miles driven but only 47 percent of travel costs. This type of travel has lower costs because a high proportion of the miles driven is in automobiles which have a low cost per mile compared to other vehicles traveling on local rural roads.

The cost of farm related traffic is high relative to the total farm miles driven. Farm related miles in the Hamilton County study area was 35 percent of total miles driven but almost 49 percent of total travel costs. Farm equipment travel costs are even higher relative to total miles driven. For example, in the Hamilton County study area, farm equipment travel--tractors, tractor-wagons and combines--had

only four percent of total miles driven but had 18 percent of total travel costs.

School bus and postal service travel represented about two percent of total miles driven in the Hamilton and Shelby County study areas, but they incurred about four percent of total travel costs.

Groups of roads were removed in each study area to estimate the benefits to the traveling public and the cost of keeping each group of roads in the study area road system. A benefit-cost ratio was then estimated for each group of roads. The benefits were defined as the savings to the traveling public from keeping the selected groups of roads in the road system. The costs in the benefit-cost ratio are the costs of keeping the roads in the system and include maintenance, resurfacing and reconstruction costs as well as the land rental value foregone--opportunity cost--by keeping the land in roads rather than in agricultural production. If the benefit-cost ratio is greater than one, the benefits to the traveling public exceed the cost of keeping the roads. If the ratio is less than one, the benefits to the traveling public are less than the cost of keeping the roads in the system. In the Hamilton and Shelby County study areas, additional groups of roads were removed from the system with the initial group of roads still out of the system. Benefit-cost ratios were then estimated for the additional groups of roads.

The estimated benefit-cost ratios varied by study area. In the Linn study area, nine miles of roads which served no property accesses were removed from the study area road network in the computer analysis

to obtain the benefit-cost ratios. The benefit-cost ratio for these nine miles was 1.37. This means that the traveling public saves $1.37 in travel costs for each dollar spent to maintain the nine miles of Linn County roads. This high ratio is basically the result of a large number of rerouted household and school bus travel miles caused by the removal of the nine miles of Linn study area roads from the computerized network. In addition, the cost of rerouting a substantial number of high cost farm vehicle miles was high. The average daily traffic on the nine miles of roads removed from the Linn study area roads was 27 vehicles per day.

In the Shelby County analysis, three groups of roads were removed from the study area with computer simulations. None of the roads served property accesses. In the first solution, called the S_1 solution, 9.25 miles were removed from the study area road network. In the second solution, called S_2, an additional 6.75 miles of road were removed from the network, resulting in a total of 16 miles removed from the network. In the third solution, called S_3, an additional 5.25 miles were removed, making a total of 21.25 miles eliminated from the system. The benefit-cost ratios for the S_1, S_2 and S_3 solutions were 0.90, 3.22 and 7.01, respectively.

In the S_1 solution, the benefits to the public from keeping the roads were about equal to the cost of keeping the roads. The traffic levels on the S_1 roads were relatively low; the average daily traffic level was only seven vehicles per day. However, the cost of rerouting the low levels of traffic in S_1 was high because the traffic was

rerouted relatively long distances over gravel roads which have high vehicle travel costs. The cost savings from removing the S_1 roads from the road system were relatively low because the rerouted traffic resulted in a large amount of variable maintenance and resurfacing costs being transferred to the roads which inherited the traffic. The largest savings from abandoning the S_1 roads were in the fixed road and bridge maintenance costs. No savings were gained from placing the land in agricultural production.

The highest benefit-cost ratios came from the S_2 and S_3 analyses. The major reasons for the high benefit-cost ratios in the S_2 and S_3 solutions were:

1. The relatively high traffic levels on the abandoned S_3 roads.
2. The small number of paved roads in the Shelby study area resulted in most of the rerouted traffic being inherited by gravel roads which have high vehicle travel costs.
3. The remaining gravel roads which inherited the rerouted S_2 and S_3 traffic incurred large increases in variable maintenance, resurfacing and reconstruction costs.
4. The land rental foregone because the land is in roads was zero.

Two sets of roads were removed from the Hamilton County study area. The first set, called H_1, included 17.75 miles of gravel roads that served no property accesses. The second set of roads, called H_2, consisted of 40 miles of gravel roads that served residence, farm

and field accesses. The H_2 roads were not abandoned, but rather were converted to private drives in the computer road network.

The benefit-cost ratios computed for the Hamilton County study area were both less than one; this means that the benefits to the traveling public for keeping the H_1 and H_2 roads in the system were less than the costs of keeping the roads in the system. The benefit-cost ratio for the H_1 solution was 0.70 for the 17.75 miles of road that served no property accesses. The H_1 roads had about the same amount of traffic per day as the roads in the S_1 solution. However, the benefit-cost ratio for the H_1 roads was lower than the S_1 miles of roads for the following reasons:

1. The cost of rerouting the H_1 traffic was lower than for the the S_1 traffic because much of the H_1 traffic was rerouted onto paved roads which have lower travel costs per mile for all vehicles.
2. The amount of H_1 household rerouted traffic per mile of abandoned road was sharply lower than in the S_1 solution.
3. The resurfacing and reconstruction costs transferred to other roads was sharply lower in the Hamilton area than in the Shelby area. This is primarily because the Hamilton County study area contains a basic network of paved roads to handle the inherited traffic.
4. The net opportunity cost of keeping the land in roads was higher in the Hamilton study area than in the Shelby study area.

In the H_2 solution, 40 miles of roads which have residence accesses as well as farm and field accesses were converted to private roads in the computerized road network. The resulting benefit-cost ratio was the lowest of all estimated benefit-cost ratios. The major reason for the low H_2 ratio is that only three of the 40 miles of public roads that were converted to private drives had traffic that was rerouted because of the conversion to private drives. The other 37 miles of H_2 roads were already dead-end roads or had become dead-end roads when the 17.75 miles of H_1 roads were abandoned and the three miles of H_2 roads were converted to private drives. Any overhead traffic on the 37 miles of dead-end H_2 roads had been rerouted in the H_1 solution or in the H_2 solution when the three miles of road with property access were abandoned. Dead-end roads can be converted to private drives at no additional travel cost because overhead traffic is already rerouted around the dead-end road. Anyone using accesses on the dead-end road can do so by traveling on the private drive. The economic issue in converting dead-end roads to private drives is the savings in maintenance costs to the county or the public compared to the cost to the landowners of maintaining private drives. The average private road and bridge maintenance cost and private road reconstruction cost was $2,064 per mile per year of H_2 private drive.

The major conclusions from the study are:

- The major sources of vehicle miles on county roads are automobiles used for household purposes and pickup truck travel for farm purposes.

- Farm related travel represents a relatively small percent of total travel miles but a relatively high percent of total travel costs.
- 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 the roads.
- In areas with a relatively small rural population and a very large percent of gravel roads, only a small number of roads with no property accesses can be abandoned before the additional travel costs from the abandonment exceed the cost savings from eliminating the roads from the system. A large number of rural southern Iowa counties do not have a basic network of paved roads to carry the traffic from the abandoned roads.
- 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 accesses can be abandoned and the savings from abandoning the roads will exceed the additional travel costs. A large share of northern Iowa counties have a relatively high percent of paved roads. A strategy of county road abandonment in these areas would result in net transportation cost savings.
- Dead-end roads with property access can be converted to private drives with no additional travel costs. Public road

maintenance costs exceed private drive maintenance costs. Therefore, a strategy of converting dead-end roads with property accesses to private drives would result in savings to the county which would exceed the maintenance and reconstruction costs to the property owners.

The public policy implications of these results are:

- There are limited potential cost savings from abandonment of county roads with no property accesses in areas with a large non-farm rural population.
- There may be potential savings from abandonment of roads with no property accesses in areas with a small rural population and a large share of gravel roads if some gravel roads are resurfaced to create a core paved network. This alternative was not explored in this analysis.
- There are relatively high potential cost savings from abandonment of roads with no property accesses in areas with a small rural population and a core network of paved roads.
- The largest potential cost savings are likely to come from conversion of public dead-end gravel roads with property or residence accesses to private drives. This potential cost savings can be achieved in all areas regardless of the population or the physical condition of the remaining roads. However, a strategy of road abandonment and conversion of dead-end roads to private drives should be carried out simultaneously. An alternative which may yield as large cost

savings as conversion to private drives is to convert low volume gravel roads with property access to lower service roads with lower maintenance costs. But this alternative was not examined in this analysis.

- In addition to all the economic costs associated with the abandonment of roads which are included in the determination of benefit-cost ratios in this study, there is one other possible cost which should be considered. There can be substantial legal costs and damage awards associated with a road abandonment. The possibility and extent of such costs depends in large part upon the state laws in effect in the various states. Since these costs vary widely from case to case, it was not possible to include these costs in the benefit-cost ratios in this study.

It is possible that present laws in some states may preclude any possibility of road abandonment even though all other costs considered, including the shifting of road costs from the public to the private sector, indicate a net benefit from such abandonments. In fact, it may require changes in state laws, along with a major change in public policy and acceptance, before any of these changes could and would be implemented and accepted. Some of the areas which need to be addressed are:

1. An adequate method of compensation for change from public to private access.

2. A method of arbitration of disputes between adjoining landowners affected by the change and/or the local government authority.
3. Exemption of the local government authority from legal action upon completion of established guidelines.
4. Legislative consideration to strengthen existing laws regarding road abandonment and changing public roads to private roads.
5. A method of educating the public of the benefits and costs of alternative road system changes to enable the public to improve the quality of its input into the policy-making process.

CHAPTER II

INTRODUCTION

For purposes of this study, the local rural road system consists of the roads that are maintained and controlled by counties or townships. The local rural road system contains over 2.2 million miles of roads and represents 71 percent of the 3.2 million miles of rural roads in the United States. It is generally laid out in rectangular grids, particularly in the midwest; the large number of miles and the regularity of the county road system date back to the Ordinance of 1785 which established townships and the one-mile survey grids. The objective of Congress was to open the land for settlement.

Many of today's local rural roads and bridges were built in the late 1800s and early 1900s when overland transportation for both passengers and freight was limited to horse and wagon or the recently built railroad lines. Farms were small, and farmers needed road access to homes, schools, churches and markets.

The discovery of large petroleum reserves in Texas and Oklahoma spurred the development of the automobile and truck industries during the 1920s and 1930s and created a need to get rural America "out of the mud." Roads were surfaced, and some bridges were replaced to accommodate trucks with gross weights of six to seven tons. About 70 percent of today's rural bridges were built before 1935. Even the bridges constructed in the 1940s were only designed for 15-ton loads.

By 1950, about 50 percent of the local rural roads were improved with all-weather gravel or paved surfaces. Thus, the widths, grades, bases, surface designs, and capacities of many local rural roads and bridges are based on the traffic needs of the 1940s and 1950s.

The declining number of farms and the increasing size of farm implements and farm trucks are changing the types of traffic on the local rural road system. There are no weight limits on "implements of husbandry"--farm equipment. Today, some farmers use a tractor and two wagons to haul 600 to 900 bushels of grain with a gross weight of 28 to 36 tons. Many bridges are 55 feet long or longer so that the entire load is on the bridge at one time. Some single axle wagons hold over 800 bushels of grain; after deducting about 6,000 pounds of hitch weight, the loaded weight ranges up to 50,000 pounds per axle.

As farm size has increased, trucks serving agriculture have become larger. Tandem axle trucks with gross weights of 27 tons are common on rural roads and bridges. In 1975, the U.S. Congress permitted states to set higher weight limits for trucks on the Interstate system. Most states have adopted the federal limits and have raised the weight limits to the federal standard of 20,000 pounds per axle, 34,000 pounds per 2-axle tandem, and 80,000-pound maximum overall weight.

The introduction of low cost unit-grain trains in the corn and wheat states has encouraged the use of larger farm vehicles to haul grain longer distances. Some farmers are buying tandem axle and semi-trailer trucks to move their grain out of the field quickly, increase their marketing options, reduce hauling costs and eliminate the safety

hazards of farm tractor-wagon combinations. But these heavy vehicles place additional stress on the local road and bridge system.

Farm size has increased steadily in recent decades. In most instances, the only way a farmer can obtain more land is to buy or lease from neighboring farms, thereby reducing the total number of farms. The large reduction in the number of farms means that some rural roads may no longer be needed for access to homes, schools, and markets. Some observers believe that the number of miles of rural roads might be reduced and still provide needed access to the remaining farms and residences.

And finally, the declining rural population has resulted in a reduction in the number of rural schools. To help minimize the cost of transporting school children longer distances to fewer schools, school boards are purchasing 72- to 89-passenger school buses. School buses of these sizes weigh up to 15 tons when loaded. These loaded buses cannot cross bridges that are posted at less than their gross weights.

Condition of the Local Rural Road and Bridge System

Precise data on the current condition of the local rural road system are not available since no ongoing coordinated data collection system exists for local roads. There is ample evidence to suggest that the system is deteriorating rapidly. In a recent Illinois survey, farmers and agribusiness representatives rated about half of the

Illinois local rural roads as needing more than regular maintenance; over 20 percent of these roads were rated as needing major repair.

Common complaints about the local rural roads include:

1. Overweight vehicles are breaking up road surfaces.
2. Lack of hard surfaces creates dust and rideability problems.
3. Road widths and other design characteristics are inadequate for today's large farm equipment and heavy trucks.
4. Narrow lanes create safety problems.

While the local road deficiencies are significant, the condition of local bridges is also of great concern. Deficient bridges on local rural roads create serious safety and traffic constraints. On January 1, 1985, 184,977 bridges or 61 percent of all the off-federal-aid bridges that had been inventoried were deficient. In addition, 118,390 or 39 percent of the 306,388 of federal-aid system bridges are posted or should have been posted at less than legal weight limits. The estimated replacement and rehabilitation costs of these deficient off-system bridges is $21 billion. However, even this understates the magnitude of the problem. Bridges under 20 feet long were not included in the inventory, and there are thousands of structures under 20 feet in length that need replacement or rehabilitation.

The distribution of deficient bridges among states indicates that the local bridge problem is national in scope. States with the largest number of deficient bridges are Texas, Iowa, Missouri, Nebraska, Oklahoma, North Carolina, Kansas, Indiana, Arkansas, Tennessee, Mississippi and Illinois. States in the Northeast, Midwest, Southeast and South-

west are included in the groups with a high percent or a large total number of deficient bridges. Western states have the least problem with bridges. The paucity of county road and bridge condition data suggests the need for statewide pavement data bank or inventory systems.

Funding for the Local Rural Road and Bridge System

Local rural road and bridge construction and maintenance funds are typically derived from highway user taxes and local property taxes. Highway user tax collections have increased recently because of large increases in fuel and truck road use taxes.

Many counties are already at the maximum level of the local tax levy and can not increase property taxes for rural roads. For example, many counties in Iowa are at the maximum and can not raise property taxes without changes in state legislation. Several counties are between 95 and 99 percent of the maximum local levy. Only a small number of Iowa counties could raise the local levy by 20 percent or more.

This means that there are major constraints on additional revenues for rebuilding the local rural road system. There are major needs for increased local rural road and bridge funding. For example, the Iowa Highway Needs Study Report indicates that the projected 1982-2001 county road revenue buying power would cover only 51 percent of the projected county road and bridge needs. While the recent higher road-use tax revenue and reduced inflation levels have marginally reduced

the gap in revenues and needs, there is little doubt that the deficit in county road revenues relative to county road and bridge needs remains very large. Counties and townships in other states as well as state departments of transportation face similar budget problems.

Alternative Solutions

The local rural road and bridge problem is basically a shortage of funds to reconstruct and maintain the present system to accommodate the changing transportation needs of rural America. Public debate about county roads has focused mainly on the deteriorating condition of the system. The implicit assumption behind much of this debate is that the system should be maintained "as is." Little attention has been given to alternative solutions to the local rural road and bridge problem. A number of alternative solutions exist, including the following:

1. Continue the present sources and levels of funds for the local rural road and bridge system.

   This alternative would mean that there would be no large increases in property or road-use taxes to finance the reconstruction of the local rural road system. However, counties and townships would continue to face increasing maintenance costs to repair existing surfaces and bridges. Moreover, many bridges would need to be closed because of no additional replacement funds. Perhaps more importantly, county and township governments could face increased exposure to large tort liability claims from damages resulting from deteriorating roads and bridges. Historically, courts have been generous to these kinds of claims.

2. Large increases in state and federal funding.

The federal government has recently levied significant increases in motor fuel and truck road-user taxes. In addition, many state governments have levied large increases in state motor fuel taxes. Part of these increased taxes have been appropriated for mass transit and a large portion of the tax increases was intended for the federal-aid system. These increased taxes have resulted in some increased funding for the local rural road system. However, these increases have fallen short of the investment requirements to keep the system "as is." Maintaining the system "as is" would require further increases in fuel and truck road-use taxes or a large allocation of the road-use tax funds to the local rural system. But many groups are lobbying to reduce the share of the road-use funds to the local rural road and bridge system.

3. Impose local option taxes alone or with bonding authority for local rural road and bridge funding.

The local option taxes could be imposed in the form of property, sales, fuel, excise and other taxes. When levied alone, local option taxes would approximate user taxes because a significant portion of the traffic on local roads is local traffic. When these taxes are used to support a bonding program for capital improvements, the program becomes a mortgage on the future and increases the total cost of the system.

4. Reduce the minimum reconstruction and maintenance standards for local rural roads and bridges.

Minimum standards for local rural roads and bridges are generally based on a design guide published by the American Association of State Highway and Transportation Officials. In some cases, road plans must be approved by state and federal agencies. Future reconstruction costs could be reduced by lowering the minimum design standards on low volume, local rural roads. Costs could be cut by reducing the widths of rights-of- way, shoulders and bridges, as well as by reducing the thickness of the pavement and maximum grades.

Lower minimum standards, on the other hand, could result in increased maintenance costs through greater erosion of steeper slopes, faster deterioration of pavements and bridges, and reduced snow storage capacities. Operating costs for the traveling public would also be increased by this action.

5. Reduce the size of the local rural road system by abandoning roads that have no property accesses and by reducing the number of property access routes.

A large portion of the Midwest and West has a rectangular road grid system. With this system, some property owners have four-way access to their farmsteads or other property because access to the property is available from each of the four roads. The possibility exists for maintaining access to property by providing one, two, or three-way access. Thus, one or more roads

could be abanoned without loss of property access. A reduction of the miles of local rural roads could be made by abandoning roads with no property accesses and roads which provide only a second or third access. In fact, some counties have a policy which provides only one all-weather surfaced access to an occupied rural residence, unless increased service is necessary to provide system continuity. While this policy does permit the use of unsurfaced roads in dry weather, it causes disruptions in school bus and mail routes in bad weather and increases travel time and costs.

The cost of keeping a road may be less than the cost of abandoning it. District courts have tended to make large awards to landowners for the loss of public access. Many county engineers believe that only a very small number of rural roads will be vacated unless laws are changed. Proposed changes in legislation would allow counties to remove a secondary or field access to property with smaller or no damage claims for the action.

6. Return some roads to private ownership.

A 1976 editorial in the Des Moines Register states:

> "County roads that served dozens of farms forty years ago may be serving only two or three farms today. Many roads that were once vital to a county's well-being have become, in effect, private roads, although the county is responsible for their upkeep. Such roads no longer belong in a county road system."

Some observers believe that returning some roads to private drives is the fundamental answer to the lack of funds for rural

road and bridge construction and maintenance. This option would preserve the access to homes, farms and fields on these roads, but it would shift the liability of accidents as well as the maintenance from the local government to the property owners along the roads.

7. Reduce and enforce weight limits on local rural roads and place weight and width limits on "implements of husbandry."

This alternative undoubtedly would reduce maintenance costs of existing roads and bridges. However, a reduction of current weight limits and placing weight and width limits on "implements of husbandry" could increase the costs of producing and moving agricultural products to market. It would also create enforcement problems. There is a need to study the reconstruction and maintenance cost of increased weight limits compared to the increased costs of agricultural production if lower weight limits were imposed.

Objectives

The basic purpose of the study is to develop guidelines for local supervisors and engineers in evaluating local rural road and bridge investment or disinvestment proposals and to provide information to state legislatures in developing local road and bridge policy proposals. The general objective of this study was to evaluate the benefits and costs of selected alternative local rural road and bridge investment strategies.

Specifically, the objectives were to:

I. Describe the county road system traffic flows in three study areas in Iowa in terms of:

   A. the number, origin, and destination of trips by households by vehicle type.

   B. the number, origin, and destination of farm-related trips by vehicle type.

II. Estimate the vehicle travel cost per mile by vehicle type and road surface.

III. Determine the costs of maintaining county bridges and county roads by surface type and traffic levels.

IV. Develop a computer program to estimate the change in travel costs and the change in road and bridge maintenance costs under alternative road investment strategies.

V. Identify, analyze, and evaluate the benefits and costs of alternative county road and bridge investment strategies.

VI. Describe the impacts of the alternative investment strategies on farm, household, local school system and post office travel costs and on county maintenance, rehabilitation and reconstruction costs.

CHAPTER III

LITERATURE REVIEW

Numerous writers have discussed the deteriorating conditions of the local rural road and bridge system. However, only a small number of studies, namely those by Chicoine and Walzer, Baumel and Schornhorst and Fruin, have attempted to identify alternative solutions. Fewer, yet, have attempted to quantify the impacts of the deteriorating roads and bridges on travel costs or the impacts of alternative solutions on travel costs and local government costs.

The Pennsylvania Department of Transportation identified an Agricultural Access Network in two Pennsylvania counties. These agricultural access networks included those roads that were judged to be most important to the rural agricultural areas for the transport of agricultural products to markets and supplies to the farms. In addition, the study identified the key transportation obstructions which currently inhibit agricultural movements.

Tucker and Johnson examined the impact of alternative rural road development and maintenance policies on grain marketing costs in southeastern Michigan. The results indicate that grain marketing costs decrease as the road system is improved, but the savings in grain transport costs were far less than the costs of the road improvements.

Nyamaah and Hitzhusen used a circuity model to estimate the rerouting costs to road users when 15 rural bridges in Ohio were posted or closed. The model indicated substantially greater benefits from bridge repair or replacement than the county engineers estimated.

Chicoine and Walzer surveyed farmers, township officials and agricultural and rural business officials in four Midwestern states to identify their opinions and attitudes on a wide range of rural road and bridge questions and issues. In addition, they identified the preferred alternative sources of rural road and bridge financing, as well as alternative investment strategies and management practices.

Smith, Wilkinson and Anschel examined the impact of unimproved roads in the eastern Kentucky coal fields on resident participation in social recreation, education and medical activities. They found that lack of access to all-weather roads had no measurable adverse effect on human resource development and cultural integration.

The Midwest Research Institute developed criteria for evaluating low volume rural roads for potential abandonment. These criteria were to be used to calculate a benefit-cost ratio for each road. The benefits were based on traffic levels, number and type of users, type of road and access requirements. Each factor was assigned an arbitrary weight and aggregated into an index. The costs of retaining a road included the 20-year routine maintenance and capital costs, liability risks and vacating costs. The benefit index does not include any monetary measures of the value of an individual road to the traveling public. This procedure does not measure the change in cost to the traveling public from eliminating a road or set of roads from the network. Moreover, it does not measure the maintenance and resurfacing costs transferred to roads that inherit additional traffic.

Johnson developed models which could be used to estimate the benefits of road improvements including building a new road, replacing and upgrading bridges, and widening or resurfacing a road. The analysis was conceptual rather than empirical, and no measured benefits are presented.

Several studies, including Hartwig and the Iowa Department of Transportation, have suggested a potential cost savings from the abandonment of local rural roads. However, no analyses were found which quantitatively evaluated the impacts of alternative road and bridge investment strategies on all traffic types on the rural road and bridge system.

CHAPTER IV

METHODS OF ANALYSIS

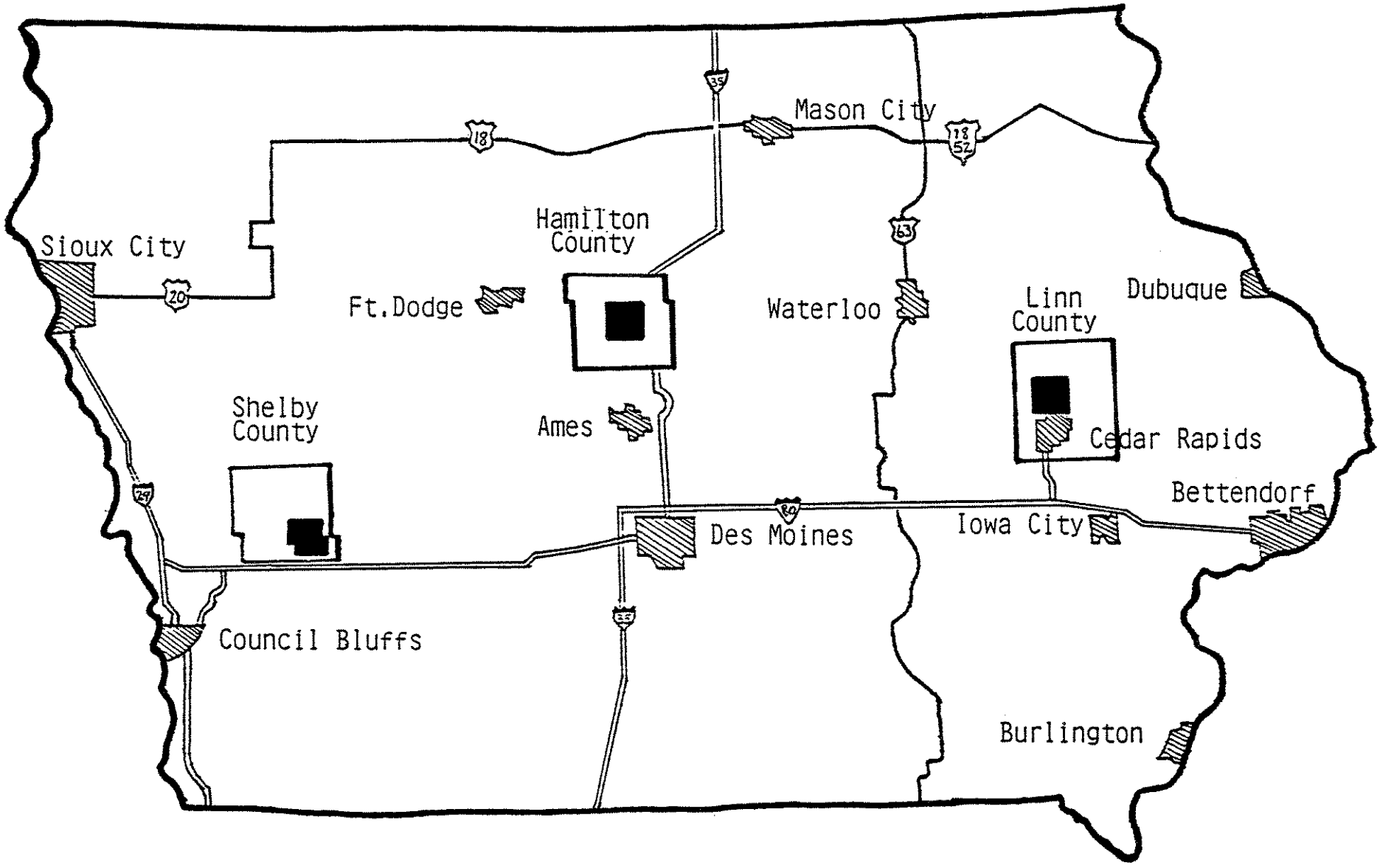
A benefit-cost method of analysis was used in this study to evaluate the benefits to the traveling public from keeping selected low traffic volume roads in the county system in three areas of approximately 100 square miles each in Iowa. The study areas, outlined in Map 1, are located in Hamilton, Shelby and Linn counties in Iowa. The three counties were selected for their differences in terrain, quality of roads and level and the type of economic activity.

1. Hamilton County, located in north central Iowa, has a relatively high agricultural tax base, relatively level terrain, a high percentage of paved roads and relatively few bridges.
2. Shelby County, located in southwest Iowa, has a relatively low agricultural tax base, hilly terrain, a small percentage of paved roads and a large number of bridges.
3. Linn County, located in east central Iowa, has a relatively high agricultural tax base, a high percentage of paved roads and a large number of non-farm households with commuters to Cedar Rapids and Waterloo.

Benefits

The benefits to the traveling public are measured as reduced traveling costs from a larger road system. If a road is removed from the

Map 1. Location of study areas.



network, some vehicles must travel further to reach the intended destination. This additional travel distance increases travel costs. This increased travel cost is the benefit to the traveling public for keeping the road in the system.

Except for school bus and post office travel costs, the benefits accruing to the traveling public were estimated in two steps. First, a network model was used to estimate the minimum cost traffic flows for all 1982 traffic within each study area. These traffic flows were then used to estimate the minimum total cost of all 1982 travel in each study area. Travel costs were defined as the variable vehicle cost per mile times the number of miles traveled by each vehicle type.

A network model, utilizing Dijkstra's algorithm, was used to estimate the minimum cost routing of traveling from each origin to each destination for each vehicle type. The advantages of Dijkstra's algorithm are that it preserves the origin-destination relationship and it requires relatively few operations to find an optimal solution. A network consists of a set of nodes connected by arcs. A node represents a point where a trip originates, is relayed or terminates. Arcs represent the road distance between two nodes and allow the traffic to flow between two nodes.

The roads in each study area were coded into a computer network. Roads became arcs, and nodes were located at intersections as well as at half-mile intervals. The following section describes the different types of arcs in the complete road network.

Study Area Arcs

The roads within each study area were divided into approximately half-mile segments. A node representing each household, farm and field access point on the half-mile arc was placed at the end of the arc. Each bridge in the study area is also represented as an arc. The actual square footage of each bridge is coded with its arc so that maintenance, repair and replacement cost will be based on the actual square footage of the bridge. The physical characteristics of each half-mile section, i.e., pavement surface, distance, and weight constraints were coded into a computer data set.

Border Area Arcs

A large number of trips from the study area to outside the study area are trips to destinations within three miles of the study area borders. Many farmers living inside the study area farm tracts of land within the three-mile border. Border area arcs were created to allow the computer to accurately route trips to destinations within the three-mile area surrounding the study boundaries. Border arcs were formed by placing a node at each road intersection in the three-mile wide border around the outside of the study area. The distance and pavement surface of these arcs were coded into the computer data set.

Outside Arcs

Outside arcs were created to allow the algorithm to route farmers through the study area when traveling to land outside of the three-mile

border area. Outside arcs were formed by placing four nodes, one north, south, east, and west of the study area and connecting these nodes to the nodes on the respective edge of the study area. For example, if a farmer had a tract of land located outside the three-mile border and south of the study area, the tract would be given the south border node as a destination. Any trips to that outside tract would be routed from the origin node within the study area to the outside node. This allowed the calculation of within-study-area cost of travel to tracts of land further than three miles outside the study area.

Highway Arcs

Many trips are to distant locations, frequently to large cities and out-of-state locations. The method used to incorporate these trips into the analysis is based on the assumption that travel routes to or from distant locations will maximize the use of state or interstate highways. One node was assigned to each state or interstate highway within the study and boundry areas. The highway nodes were connected to nodes serving as access points to the highway with a zero distance for all vehicles. The computer routed the trip to the closest access to a state or federal highway which lies in the general direction of the true destination or origin.

Tract Arcs

The origin or destination of many farmer trips are tracts of land. Tracts of farm land often have multiple access points. In most cases,

the access used depended on the direction of the trip origin. Each tract of land was assigned a node number. When a farmer traveled from tract to tract, the origin and destination were coded as the tract's node number. The computer then found the cost minimizing route between the two tracts by finding the optimal access points to use for each trip. Tract arcs were given a distance of 100 miles so that only trips which had that tract node as an origin or destination would be routed over the arc. This essentially prevents road traffic from "driving through the field." When calculating the actual cost of a given trip, the 100 miles to travel on a tract arc was set equal to zero.

Network Constraints

A separate computer program was developed to check the weight limit of each study area bridge with the weights of the vehicles in the study area. If the weight of the vehicle exceeded the weight constraint of the bridge weight, the arc distance or cost was set equal to a large number before the routing began. For example, if a bridge has a posted load limit of 10 tons and the vehicle type has a weight exceeding 10 tons, then the bridge arc was assigned a large distance for all trips involving that vehicle type.

The 1982 travel data taken from the questionnaires obtained from the study area residents and farmers were coded into the computer network. The computer then optimized the routings for all 1982 trips to obtain the least cost routings of all 1982 travel in the study areas.

The basic assumptions behind the network model used in this analysis are:

1. Travel costs are a linear function of distance traveled for each vehicle type.
2. The number of trips from each origin to each destination in each time period by each vehicle type is independent of changes in the road system.
3. Vehicle purchase decisions are not affected by the changes in the distance between an origin and a destination resulting from a change in the road system. The changes in distance are generally small.
4. Vehicle trips leaving a specific origin for a specific destination must leave that origin and arrive at that destination.
5. Vehicle drivers select travel routes to minimize travel costs.
6. Vehicles with gross weight greater than the posted carrying capacity of a bridge cannot cross that bridge.

Detailed specifications of the network model are presented in Appendix A.

The second step in estimating the benefits was to reoptimize the traffic flow to obtain the minimum total cost of all 1982 travel under the assumption that selected roads were eliminated from the system. In most cases, eliminating roads from the system will increase travel miles and costs. Thus, the difference between the total cost of travel

under the smaller size road system obtained in step 2 and the cost under the original road system from step 1 is defined as the savings to the traveling public from keeping the analyzed roads in the study area system.

School bus and post office travel costs could not be estimated by the network model because much of the routing of these vehicle depends on how the routes were structured outside the study areas. Alternative methods were used to estimate the benefits to these vehicles from keeping the selected road in the system. After selected roads were removed from the system, existing school bus routes were rerouted visually to estimate travel costs. Postal service travel costs before and after the selected roads were eliminated from the system were estimated by officials from the U.S. Post Office in Des Moines based on postal routes inside and outside each study area.

Costs

The cost portion of the benefit-cost ratio is defined as the annual cost of keeping the abandoned roads in the system. These costs include:

1. fixed maintenance costs which are associated with time and weather,
2. variable maintenance costs caused by vehicle traffic,
3. the annualized cost of periodic resurfacing and reconstruction and,

4. the net opportunity cost of having the land in roads rather than in agricultural production.

Annual fixed maintenance costs on paved roads include drainage, signing and major maintenance ditching; these costs are independent of traffic volume. Variable maintenance costs on paved roads include snow removal, resurfacing, painting lane stripes, patching, and shoulder resurfacing. Variable maintenance costs on paved roads vary by surface type and thickness, subbase thickness, number and weight of vehicle axles, and number of vehicle axle passes.

Fixed costs on granular roads include signing, drainage, snow removal and weed control. Variable maintenance costs on granular surface roads include gravel resurfacing and bladeing. No estimates of the impact of vehicle axle weight are available on granular and earth surfaced roads. Major reconstruction and resurfacing costs vary by type of road and traffic volume. The computer program for estimating maintenance, resurfacing and reconstruction costs is presented in Appendix B.

The Data

This section describes the data needed to compute the benefit-cost ratios, the data collection method and a summary of the collected data. The basic road and bridge investment strategy evaluated in this study was to reduce the number of roads in each of the three study areas. Benefit-cost ratios were computed for each study area under the assumption that the road system would be reduced by eliminating roads with no

property or household access points. In addition, one benefit-cost ratio was computed in the Hamilton County study area under the assumption that a set of roads that have property and field access points would be converted into private roads. The data required to estimate these benefit-cost ratios include the following:

1. The quantity, origins and destinations of all household and farm travel by vehicle type that originate or terminate within the study areas.
2. The quantity and types of overhead traffic that move through but do not originate or terminate in the study areas.
3. The travel costs of each type of vehicle traveling in the study areas.
4. The miles and types of roads and the number and sizes of bridges within the study areas.
5. The cost of maintaining and rebuilding the roads and bridges in the study areas.

Quantity and Types of Travel in the Study Areas

Data on personal and farm travel were obtained by a traffic survey of households and farms in the three study areas. The survey was conducted by the Iowa State University Statistical Laboratory. All interviews were conducted by professional interviewers.

The goal of the survey was to obtain data on 1982 travel from all farm and non-farm residents in the three study areas. The first round of farm interviewing accounted for about 75 percent of the farm land

within the study area borders. By mapping out the land covered by the completed questionnaires, examining platt books and questioning neighbors, the majority of the land not listed in the questionnaires was found to be farmed by operators who lived outside the ten-mile by ten-mile study areas. Farmers who operated the farm land not covered in the initial round of interviews were located and interviewed. These farmers who lived outside the study areas but farmed land within the study areas are referred to as nonresident farmers in the remainder of this paper.

Only five out of 231 farmers operating in the Hamilton County study area, 11 out of 274 farmers operating in the Shelby County study area and 10 out of 248 farmers operating in the Linn County study area refused to be interviewed. Thus, the farm interview rate was 97.8 percent in Hamilton County and 96 percent in Shelby and Linn counties. Neighbors were questioned about the farming characteristics of the refusing farmers. Information gathered from neighbors, along with questionnaire responses from nearby farmers with similar size farms, were used to construct questionnaires for the refusing farms. Residents who died or moved out of the area since 1982 were also accounted for by interviewing neighbors and friends. Questionnaires from respondents with similar characteristics were then substituted for these residents.

All non-farm rural households in the Hamilton and Shelby study areas were targeted to be interviewed. Only eight out of 125 non-farm households in the Hamilton County study area and 10 out of 170 non-farm

households in the Shelby County study area refused to be interviewed. Thus, the non-farm household interview rate was 93.6 percent in Hamilton County and 94.1 percent in Shelby County. Neighbors were questioned about the characteristics of households that refused to be interviewed or residents who died or moved out of the study area since 1982. Responses from questionnaires obtained from nearby households of similar size and type were used for the missing households.

Time and money constraints prohibited interviewing the many non-farm rural households in the Linn County study area. Therefore, a sampling procedure was devised to obtain data from these households. First, a "windshield" survey of the entire Linn County study area was made to pre-identify farm and non-farm households. Of the 445 identified farm households, 245 turned out to be non-farm households. All of these households were asked for an interview. A total of 14 households refused to be interviewed, resulting in a 94 percent response rate. A random area sample of the remaining non-farm households was drawn at a sampling rate of one out of 12. Only 12 sampled non-farm households refused to be interviewed for an 83 percent response rate. The 59 non-farm interviews were then expanded 11 times at the location of each of the 59 interviewed locations; that is, the responses on each questionnaire were assigned to 11 additional households located at the same node as the interviewed household.

The Hamilton and Linn study areas each contained one incorporated town. Data on travel patterns of residents of these towns were obtained by an area sample of households. One household was sampled for

every 11 households. Data for the remaining households were obtained by expanding the sampled questionnaires.

Table 1 presents a summary of the number and type of interviews by study area. The total number of farms was nearly identical in each of the three study areas. The total number of farm and non-farm households was almost exactly the same in the Hamilton and Shelby County areas. However, the Linn County study area had about four times as many households as the Hamilton and Shelby County study areas.

A major effort was made to validate the questionnaire response and interviewer quality. Telephone calls were made to 10 percent of the households and farms interviewed by each interviewer to validate the initial questionnaires. The answers obtained through the validation calls were essentially the same as the initial answers. In addition, all discrepancies between answers within questionnaires or unclear responses were resolved by telephone calls to the initial respondents.

Separate questionnaires were developed for farm and non-farm respondents. A summary of the main information requested in the questionnaires is presented in Table 2. The farm questionnaire asked for all the information contained in Table 2. The non-farm questionnaire asked for information on items 1 and 14-17 in Table 2. Copies of the farm and non-farm questionnaires are presented in Appendix E.

Partial Survey Results

Responses to the questionnaires provided a large amount of information on farm and non-farm travel patterns. Tables 3, 4 and 5 summarize selected sets of the questionnaire data.

Table 1. Summary of farm and non-farm interviews and sample expansion in the Hamilton, Shelby and Linn County study areas.

Description	Hamilton		Shelby		Linn	
	Households	Farms	Households	Farms	Households	Farms
Study area farm interviews	170	170	196	196	195	195
Nonresident farm interviews	*	56	*	67	*	43
Farm refusals**	4	5	6	11	5	10
Rural non-farm interviews	110	--	160	--	231	--
Rural non-farm refusals	8	--	10	--	14	--
Town household sample interviews	7	--	--	--	18	--
Small town household expansion	80	--	--	--	198	--
Linn County non-farm sample interviews	--	--	--	--	59	--
Linn County sample refusals	--	--	--	--	12	--
Linn County non-farm sample expansion	--	--	--	--	781	--
TOTAL	379	231	372	274	1513	248

*Household travel information was not taken for nonresident farmers.

**Includes nonresident farm refusals.

Table 2. Summary of information requested on the questionnaires.

Information requested

1. Exact location of respondent's home and land tracts.
2. Number of acres in each tract.
3. Access points for each land tract.
4. Location of land tracts outside study area.
5. Information about a farming partner, if applicable.
6. Deliveries made to each tract.
   a) Number of deliveries.
   b) Name and location of dealer making the delivery.
   c) Type of vehicle used for deliveries.
7. Alternate routes (those different than the shortest route).
8. Origin, destination and number of pickup truck trips by farmers.
   a) Tract-to-tract travel.
   b) Off-farm travel.
9. Origin and destination of farm equipment travel from one tract to another tract.
   a) Type of vehicle.
   b) Number of times vehicle entered each tract.
10. Number and size of combines used.
11. Number and size of tractors used.
12. Total number size of trucks.
13. Intra-farm and off-farm product hauling.
   a) Products hauled.
   b) Number of trips.
   c) Destination of hauling.
   d) Type of vehicle.
14. Demographic information.
15. Detailed information on personal travel.
16. Deliveries made to the house.
   a) Number of trips.
   b) Origin of trips.
   c) Type of vehicle.
17. Traffic coming onto homestead.
   a) Number of visitors.
   b) Origin of the traffic.
   c) Type of vehicle.

Table 3. Distribution of number of tracts per farm and average acres per farm in each tract group by county study area.*

Study area	Number of tracts	Average acres per farm	Percent of total acres	Number of farmers	Percent of total farmers
Hamilton	1	137	8.0	40	23.0
	2	225	13.5	41	23.6
	3-5	465	48.1	71	40.8
	6-8	791	18.4	16	9.2
	9-11	1,229	5.4	3	1.7
	12-14	1,500	6.6	3	1.7
Shelby	1	142	11.0	52	25.7
	2	243	18.9	52	25.7
	3-5	435	55.3	85	42.1
	6-8	772	13.9	12	6.0
	9-11	611	0.9	1	0.5
Linn	1	86	10.5	70	35.0
	2	144	10.6	42	21.0
	3-5	293	30.8	60	30.0
	6-8	719	21.4	17	8.5
	9-11	1,000	8.8	5	2.5
	12-14	1,233	10.8	5	2.5
	32	4,044	7.1	1	0.5

*Excludes nonresident farmers.

Table 3 presents the distribution of the number of spatially separated tracts of land operated by individual farmers. The distance separating multiple tract farms is a major determinant of the amount of road travel by farmers to plant, cultivate, harvest, and haul the crops to market or to on-farm storage. Single tract farms require little, if any, road travel to reach the fields.

The percent of farmers operating single tract farms was 23.0 percent in Hamilton County, 25.7 percent in Shelby County and 35.0 percent in Linn County. These single tract farmers, with an average of 137 and 142 acres per farm in the Hamilton and Shelby study areas and 86 acres per farm in the Linn County area, operated a disproportionately small percent of the total farm acres in the three study areas. Out of the total acres of farmland in the three study areas that were farmed by study area residents, only 8.0, 11.0 and 10.5 percent were operated as single tract farms in the Hamilton, Shelby and Linn study areas, respectively.

Two-tract farms made up 23.6, 25.7 and 21.0 percent of the resident farmed land in the Hamilton, Shelby and Linn study areas, respectively. The average size of the two-tract farm was over 200 acres. The largest percent of farmers in the Hamilton and Shelby study areas--40.8 percent in Hamilton and 42 percent in Shelby--operated three to five tracts of land. Farms of six or more tracts of land contained 30, 15 and 48 percent of the land farmed by resident farmers in the Hamilton, Shelby and Linn County study areas. The Linn County study area had the

largest percent of single tract farms as well as the largest percent of very large farms.

Table 4 presents the total and average number of vehicles used on resident farms in the three study areas. As expected, the most numerous vehicle used was the farm tractor. There were 924 tractors in the Hamilton County study area, nearly 1,200 tractors in the Shelby County area, and 841 tractors in the Linn County study area for an average of 4.1, 4.5 and 3.2 tractors per farm, respectively. The second most numerous vehicle used was the pickup truck averaging between 1.2 and 1.5 pickup trucks per farm. The most numerous large truck used was the single axle truck; one out of three Hamilton County study area farmers, one out of two Shelby County study area farmers, and two out of five Linn County study area farmers had a single axle truck.

The Shelby and Linn study area farmers owned more trucks of all sizes than the Hamilton study area farmers. One might conclude that the absence of any railroad lines in Shelby County could be the reason for the large number of trucks in the Shelby study area. However, the Linn County study area had more large trucks than the other two areas, and Linn County has more railroad lines than Hamilton County and, indeed, more railroad lines than most Iowa counties. A more reasonable explanation for the large number of trucks in the Linn and Shelby study areas may be the location of major grain markets at Cedar Rapids and Clinton for the Linn County farmers, and at Council Bluffs and Omaha for Shelby County farmers. Grain farmers in Hamilton County sell most of their grain through unit-train grain elevators which are typically located within 10 miles of most farms in the Hamilton study area.

Table 4. Average, total and maximum number of vehicles per farm by type of vehicle and study area.*

Study area	Type of vehicle	Total number of vehicles	Average vehicles per farm	Maximum number of vehicles per farm
Hamilton	Tractor	924	4.1	10
	Pickup	336	1.5	9
	Single axle truck	68	0.3	4
	Tandem axle truck	32	0.2	3
	Semitrailer truck	3	0.01	1
Shelby	Tractor	1,194	4.5	9
	Pickup	475	1.4	9
	Single axle truck	120	0.5	3
	Tandem axle truck	47	0.2	4
	Semitrailer truck	14	0.05	4
Linn	Tractor	841	3.2	15
	Pickup	320	1.2	8
	Single axle truck	101	0.4	6
	Tandem axle truck	50	0.2	6
	Semitrailer truck	17	0.07	5

*Excludes nonresident farmers.

Table 5 presents the average number of personal trips per household per day in the three study areas. The percent of households with less than one personal trip per day ranged from 21 percent in the Linn study area to 40 percent in the Shelby study area. About one-third of the households in all three areas made 1.0 to 1.9 personal trips per day. The percent of households with two or more trips per day was 28 percent in the Shelby area, 38 percent in the Hamilton area, and 46 percent in the Linn area. Thus, the Linn area had the largest number of trips per day, followed by Hamilton and then Shelby.

Table 6 presents the total number and age distribution of the residents in the three study areas. The Linn County area has about eight times as many non-farm residents as the Hamilton and Shelby areas. Moreover, a much higher percent of the Linn non-farm residents are less than 50 years old.

The total number of farm residents ranged from 533 in the Hamilton study area to 639 in the Shelby area. With the exception of the Linn study area residents, the farm groups had a lower share of their population over 59 years of age. The age distribution data suggest that farm personal travel as a percent of total travel should be higher than non-farm personal travel. However, the data on number of trips per day indicate that the non-farm population use the county roads for personal travel more often than the farm population.

Table 5. Number of personal trips per household per day by county study area.

Average number of trips per day	Study area: Hamilton, Number of households	Hamilton, Percent of households	Shelby, Number of households	Shelby, Percent of households	Linn, Number of households	Linn, Percent of households
0 - 0.9	98	25.8	150	40.4	324	21.4
1 - 1.9	139	36.6	118	31.7	496	32.7
2 - 2.9	60	15.9	55	14.8	345	22.8
3 - 3.9	35	9.2	29	7.8	153	10.1
4 - 4.9	21	5.5	10	2.7	109	7.2
5 - 5.9	16	4.3	2	0.5	30	2.0
6 - 6.9	3	0.8	2	0.5	16	1.1
7 - 7.9	3	0.8	3	0.8	11	0.7
8 - 8.9	3	0.8	0	0	1	0.1
9 - 9.9	1	0.3	0	0	13	0.9
10+	0	0	3	0.8	15	1.0
Total	379	100	372	100	1,513	100

Table 6. Percent age distribution and total number of residents in the three study areas.

Age in years	Percent of residents					
	Farm			Non-farm		
	Hamilton	Shelby	Linn	Hamilton	Shelby	Linn
0 - 5	6.9	7.2	8.1	5.3	10.3	9.7
6 - 15	13.1	16.6	16.0	13.8	13.6	17.2
16 - 19	9.9	9.2	9.2	6.7	6.0	9.2
20 - 29	17.5	13.8	12.6	11.4	20.3	15.2
30 - 39	9.4	11.9	14.2	14.4	11.2	17.2
40 - 49	15.4	13.5	11.0	5.3	8.6	14.5
50 - 59	18.8	14.4	12.9	18.2	6.9	5.8
60 +	9.0	13.4	16.0	24.9	23.1	11.2
Total	100.0	100.0	100.0	100.0	100.0	100.0
Total number of residents	533	639	619	507	464	3,913

Other Travel Data

The farm and household survey data and the post office and school bus data provided information on all traffic originating and/or terminating within each study area. However, these data did not include information on overhead traffic which traveled through but did not originate or terminate in the areas.

Omission of overhead traffic was thought to be most serious in the Linn County area because of traffic which might be commuting through the study area to and from Cedar Rapids. Therefore, an agreement was reached with the Iowa Department of Transportation and the Linn County

engineers office to conduct an overhead traffic survey in the Linn study area. Two locations on paved roads and one location on a gravel road were selected to conduct a "stop and go" survey.

All vehicles passing the survey location were stopped and asked their entry and exit points in the study areas. In addition, the type of vehicle was recorded. The drivers were also asked if they lived in the Linn County study area; if they did, their traffic was not counted. The vehicles were stopped and the drivers were asked these questions from 7:00 a.m. to 1:00 p.m. on one day and 1:00 p.m. to 7:00 p.m. on the following day. Automatic counters were placed at these locations from 7:00 p.m. until 7:00 a.m. the next day. The collected data were expanded to annual traffic estimates by multiplying by a conversion factor of 1.017 times 365 days. The conversion factor was obtained from the Iowa Department of Transportation and was an average for the state.

Study Area Road Systems

The three study areas chosen in Hamilton, Shelby and Linn Counties each measured ten miles by ten miles. In addition, a border area of three miles on all sides of each study area was included in the model. However, the only traffic considered in the three-mile border area was traffic originating or terminating in the study area that terminated or originated in the border areas. Table 7 presents the number of miles of road by type of surface in each study area and border area.

The data in Table 7 indicate that the quality of the county road systems is higher in the Hamilton and Linn study areas than in the Shelby study area. Over one-fourth of the Hamilton and Linn study area roads are paved, compared to only 11 percent paved in the Shelby area. Over one-half of the Shelby County study area roads were oil or earth surfaced, whereas the Hamilton study area had no oil surfaced roads and only one percent earth surfaced roads. The Linn study area had no oiled roads and only four percent earth surfaced roads.

Table 7. Miles of road in each study and border area by type of of surface.

	Study area					
	Hamilton		Shelby		Linn	
Type of road	Miles	Percent	Miles	Percent	Miles	Percent
Study area						
Paved	57.5	28.5	23.5	11.5	56.2	26.0
Gravel	142.2	70.5	75.0	36.7	151.2	70.0
Earth	2.0	1.0	31.7	15.5	8.7	4.0
Oiled	0	0	74.2	36.3	0	0
Total	201.7	100.0	204.4	100.0	216.1	100.0
Border area						
Paved	120.7	41.4	99.0	34.3	82.3	35.1
Gravel	170.0	58.4	116.0	40.2	148.5	63.2
Earth	0.5	0.2	28.0	9.7	4.0	1.7
Oiled	0	0	45.5	15.8	0	0
Total	291.2	100.0	288.5	100.0	234.8	100.0

Unpaved Road Maintenance Costs

No published or unpublished research was found on unpaved road maintenance costs. Therefore, the unpaved road maintenance cost estimates used in this analysis were developed from data provided by the county engineers in the three study areas. Table 8 presents the cost per unit used to develop the annual maintenance cost per year.

Table 8. Estimated maintenance costs per ton or per mile on gravel roads by study area, 1982.

Type of cost	Study area		
	Hamilton	Shelby	Linn
Gravel per ton	$3.67	$8.00	$ 7.00
Bladeing per mile per pass	21.00	21.00	21.00
Snow removal per mile	475.70	475.70	475.70
Signing per mile	100.00	100.00	100.00
Culvert repairs, weed control and minor ditching per mile	300.00	300.00	300.00
Culvert replacement per mile	200.00	200.00	200.00
Major ditching removal of 400 cubic yards of dirt per mile	800.00	800.00	800.00

Gravel and bladeing costs are assumed to vary with traffic levels. All other costs are assumed to be independent of traffic levels. The major differences in the cost equations is the variance in gravel costs per ton which are a result of the distance gravel must be transported, terrain and frequency of maintenance activity.

The county engineer in each study area county used the cost data in Table 8 to estimate the following maintenance cost equations for gravel roads in each of the three study areas:

$$C_H = \$2,370 + \$4.70X \quad (1)$$

$$C_S = 2,765 + 8.75X \quad (2)$$

$$C_L = 2,525 + 6.25X \quad (3)$$

where:

C_H = annual maintenance cost on gravel roads in Hamilton County;

C_S = annual maintenance cost on gravel roads in Shelby County;

C_L = annual maintenance cost on gravel roads in Linn County;

X = average number of vehicles per day.

The maintenance cost equation for earth surfaced roads was estimated by eliminating gravel costs from the Hamilton study area estimates in Table 8. The resulting cost equation for earth surfaces is:

$$C_D = \$2,026 + \$1.52X \quad (4)$$

where:

C_D = average earth and oiled surfaced road maintenance cost in each of the three study areas.

No data were available on oil surface roads maintenance costs. Therefore, the earth surface maintenance cost function was used for oil surface roads.

Paved Road Maintenance Costs

The annual fixed maintenance costs for paved roads included shoulder maintenance, striping and painting, patch and crack-filling, signing, drainage, and weed control. The paved road fixed maintenance costs for each county, estimated by the county engineer in each study area, are as follows:

County	Paved road annual fixed maintenance costs
Hamilton	$1,160
Shelby	1,083
Linn	1,400

The Iowa Department of Transportation reports average total annual maintenance costs by county and surface type. The annual paved road fixed costs per mile were subtracted from the Iowa Department of Transportation average 1982 total paved road maintenance costs; the remainder was defined as the average annual paved road variable maintenance cost. The average variable maintenance costs were then assigned to the paved roads in the study in proportion to the type of vehicles traveling on that road in the following manner:

1. Data were collected on the design term, structural number, slab thickness and type of pavement for all paved roads in the three study areas. The design term is an indicator of the effective thickness of the surface, base and subbase of the road. It was used to calculate the remaining 18-kip applications to the road before resurfacing is required. The total lifetime 18-kip

applications were divided by the expected life of the road to obtain a yearly 18-kip load application for the road. An 18-kip is an 18,000 lb. weight pass over the road surface. The structural number was used to determine the 18-kip equivalence of all single and tandem axle loadings on flexible pavements and the slab thickness was used to estimate the 18-kip equivalance of all single and tandem axle loadings on rigid pavements.

2. Data on the type of axle and weight on each axle were collected for all vehicles traveling in the three study areas. The axle type and weight, along with the structural number and slab thickness were used to calculate the number of 18-kip loads each vehicle applies to a road with each pass.
3. The number of trips each type of vehicle makes on each road was obtained from the traffic flow estimates from the network model. The number of trips per year by each vehicle type on each road was multiplied by the appropriate 18-kip equivalence to estimate the number of 18-kip applications to each road in 1982. The number of 18-kip applications was summed over all vehicles to obtain the total number of 18-kips applied to each road in 1982.
4. The total number of 18-kip applications in 1982 was divided by the average annual kip application remaining in the road and then multiplied by the average variable maintenance costs of that road to estimate the variable maintenance costs for that road.

This procedure accounted for the weight application of different vehicle types on different road surfaces. It also provided estimates of

the change in variable maintenance costs on roads that have increased or decreased traffic resulting from different county road investment strategies.

Resurfacing and Reconstruction Costs

In addition to annual maintenance costs, roads must be periodically resurfaced and, less often, completely reconstructed. Table 9 shows the frequency which resurfacing and reconstruction costs were charged to different type of roads. The resurfacing and reconstructing costs for each type of road were obtained from the Iowa Department of Transportation and were converted to annual costs by a capital recovery forumla using a 1982 real interest rate of 5.6 percent per year. The detailed procedures for estimating maintenance, reconstruction and resurfacing costs are presented in Appendix B.

Table 9. Frequency of road resurfacing and reconstruction by road surface in years.

Surface type	Frequency in years	
	Resurfacing	Reconstruction
Paved	15	50
Gravel	20	60
Earth	--	60

Private Drive Maintenance and Reconstruction Costs

Maintenance cost data for private roads were obtained on six private drives that had been converted from public roads or private drives constructed by the Iowa Department of Transportation and turned over to private ownership in Iowa. Two private drives serve non-farm households, two serve small to medium size farms, one serves a large farm and one serves a field access drive only. The maintenance costs obtained from the owners or residents of these properties are presented in Table 10. The average annual maintenance costs were $1,437 per mile for private drives serving households only, $1,509 per mile for drives serving small to medium size farms, $2,382 per mile for a private drive serving a large farm and $460 per mile for a drive serving fields only. In addition to annual maintenance costs, the private drives in the Hamilton County study area were charged a reconstruction cost of $7,824 per mile annualized over 60 years.

A large share of the annual private drive maintenance costs was for resurfacing and grading. The relatively small difference between maintaining a residence driveway compared to drives serving small to medium size farm drives is probably due to the cost efficiencies of having a tractor front-end loader, sprayer and mower on the farms. Thus, even though the traffic is heavier on the farm drives, the annual maintenance cost is only slightly higher than on residence drives.

Table 10. Estimated annual maintenance cost on private roads by type of access.

Type of access	Length of private road in feet	Annual maintenance costs: Rock	Grading	Snow removal	Weed control	Drainage	Total per year	Per mile annual conversion factor	Estimated annual cost per mile per year	Average annual cost by type of access
Residences only										
Residence I	250	$66	--	$ 5	--	--	$71	0.04735	$1,500	
										$1,431
Residence II	450	106	$10	--	--	--	116	0.08523	1,361	
Small to medium size farms with households										
Farm I										
350 acres-crops and pasture	300	87	--	--	$ 5	--	92	0.05682	1,619	
Farm II										1,509
130 acres-crops	1,320	60	120	80	60	30	350	0.25	1,400	
Large farm with household										
1,300 acres, 3,500 hogs	2,120	428	375	75	50	25*	953	0.4	2,382	2,382
Field access only 360 acres	2,640	20	150	25*	25*	10*	230	0.5	460	460

*Added to costs reported by farmer.

Bridges in the Study Areas

Table 11 presents data on bridge numbers, size, and conditions in the three study areas. The Shelby and Linn study areas have the largest number, the largest average size and the most bridges having load ratings below the legal limit of 40 tons. Bridge maintenance costs in the three study areas were estimated by the county engineers to be 80 cents per square foot annually to keep the bridges in an "as is" condition.

Table 11. Total number, size and condition of the bridges in the Hamilton, Shelby and Linn study areas.

	Hamilton	Shelby	Linn
Number of bridges	31	58	59
Average bridge size in square feet	785	1,830	1,537
Smallest bridge in square feet	288	390	174
Largest bridge in square feet	2,000	7,025	6,419
Number of bridges with less than 40 tons load rating	3	46	36

Vehicle Travel Costs

Over 100 different types of vehicles traveled over the county roads in the three study areas. Farm tractors alone were reported to pull 25 different types of trailing equipment or wagons. In addition, there were many different sizes of the same type of vehicle such as combines and tractors. The large number of vehicles made it necessary

to group several different types of vehicles together and to estimate costs for a typical vehicle in the group.

Travel costs per mile were estimated for all major groups of vehicles traveling on the county roads in the three study areas. The major vehicle groups are automobiles, pickup trucks, school buses, commercially owned vans and trucks, garbage trucks, farmer-owned single axle, tandem axle and semitrailer trucks, farm combines, and farm tractors pulling grain wagons or farm tillage equipment.

Variable operating costs per mile were estimated for each of these vehicle groups operating on paved, gravel and earth surface roads. Variable operating costs include fuel, oil, tires, maintenance and travel time. These costs reflect the marginal cost of driving an additional mile on each of the three types of road surfaces. Fixed costs including time-related depreciation, insurance and licenses were not included in the operating costs because they are largely independent of vehicle miles. There is a small component of insurance premiums that is mileage-related, but this cost also varies by driver age and sex and purpose and distance of the trip. The large number of variables affecting the small amount of mileage-related insurance costs essentially made it impossible to build these costs into the analysis.

Variable costs are assumed to be a linear function of the number of miles traveled on each surface type. Therefore, all estimated costs are estimated in cents per mile. The costs are based on 1982 prices and representative vehicles. In cases where 1982 prices were not available, the non-1982 prices were adjusted to 1982 price levels.

The data used to develop the variable cost functions were gathered from three general sources of data. First, published and unpublished research were used whenever possible. Second, industry sources such as automotive, truck, and farm equipment manufacturers and dealers, tire manufacturers and dealers, automotive parts and petroleum dealers, and truck and farm equipment owners were asked to provide the necessary data. Third, experts such as agricultural engineers, industry executives, and researchers were asked to provide data not available elsewhere. In some cases, one of these general data sources provided all the necessary data. In other instances, a combination of the three sources was used to provide the appropriate information.

The prices and data collected were not collected from random samples because random sample data were not available. Consequently, no variances or other statistical measures relating to the distribution of the cost estimates are provided. The details of the estimation procedure are presented in Appendix C.

The data were generally gathered for a typical "representative" vehicle traveling on rural road surfaces and not for the spectrum of each vehicle type. For example, the data used to develop the automobile variable cost per mile reflect operating characteristics of a 1978 3,500 lb. automobile, such as a Chevrolet Caprice Classic; the pickup truck data reflect operating characteristics of a 1978 3,500 lb. pickup truck, such as a 360 cubic inch V-8 Dodge pickup truck. The selection of the representative vehicles used to develop the variable cost estimates was based upon frequency distributions of vehicle types

obtained from the county vehicle registration files along with personal communications with public and private sector sources.

Variable costs per mile were estimated for empty and loaded travel for trucks and farm tractors pulling wagons. The cost estimates for these vehicles presented in Tables 12 and 13 are averages of loaded and empty variable cost per mile. Table 12 presents the estimated total variable cost in cents per mile for road vehicles on paved, gravel and earth surfaces. The automobile and the pickup truck, chosen to represent the 1982 fleet of cars, had variable costs of 20 and 24 cents per mile on paved surfaces, respectively. Vehicles with variable costs between 31.2 to 39.8 cents per mile on paved surfaces include school buses, pickup trucks pulling a trailer, farmer-owned single axle trucks, tandem axle trucks, and semitrailers. Commercial vans and semitrailer truck variable costs were 40.2 and 53.5 cents per mile, respectively. The primary reason that commercial trucks had higher costs per mile than farmer-owned trucks was the wage rate charged for trucks. The wage rates used were $3.60 per hour for farmer-owned trucks and $8.60 per hour for commercial trucks. These are the typical non-union wage rates paid in 1982 in rural areas and they are significantly lower than union wage rates.

Virtually all variable cost components were higher for garbage trucks than for all other road vehicles. The costs are higher primarily because of the continuous "stop and go" travel pattern of garbage trucks.

Table 12. Estimated 1982 road vehicle variable cost in cents per mile by vehicle and surface type.

Vehicle type	Cost per mile		
	Paved	Gravel	Earth
Automobile	20.2	28.3	36.4
Pickup truck	24.4	33.8	43.2
Pickup truck pulling a trailer	35.3	48.9	62.6
Commercial van	40.2	55.8	71.3
Commercial semitrailer truck*	53.5	80.3	107.1
Garbage truck	77.2	112.4	147.7
School bus	31.2	45.6	59.7
Farmer-owned single axle truck*			
Truck alone	32.3	45.9	59.6
Pulling pup	38.4	54.6	70.8
Pulling grain wagon	35.9	51.1	66.2
Farmer-owned tandem axle truck*			
Truck alone	38.4	56.0	73.6
Pulling pup trailer	47.5	69.2	90.9
Pulling grain wagon	45.0	65.6	86.2
Farmer-owned semitrailer truck*	39.8	59.7	79.7

*Assumes 50 percent of travel is loaded and 50 percent of travel is unloaded.

The cost per mile was lowest for all vehicles on paved surfaces. Costs per mile for automobiles, pickup trucks, and commercial vans increased 38 to 40 percent on gravel surfaces and 77 to 80 percent on earth surfaces.

The costs per mile for the garbage truck and single and tandem axle trucks increased 42 to 45 percent on gravel and 84 to 91 percent

on earth surfaces. Semitrailer costs increased 50 percent on gravel and 100 percent on earth surfaces over paved surfaces.

Table 13 presents the estimated total variable costs in cents per mile for paved and gravel surfaces by size of farm tractor and type of vehicle pulled by the tractor. The cost on paved surfaces for a tractor with no trailing vehicle ranged from 100 cents per mile for a 60 h.p. tractor to 184 cents per mile for the 185 h.p. tractor. Thus, the variable cost per mile increased 84 percent with the size of the tractor.

Table 13. Estimated 1982 variable farm tractor travel costs in cents per mile by tractor size, type of trailing equipment and road surface.

Equipment or wagon being pulled	Tractor size							
	60 HP		100 HP		140 HP		185 HP	
	Paved	Gravel	Paved	Gravel	Paved	Gravel	Paved	Gravel
Tractor alone	100.1	112.6	123.5	139.7	138.2	157.1	184.4	207.4
Farm machinery	100.8	113.9	124.6	141.7	139.7	160.1	186.6	211.7
Grain wagons								
125-bushel*	100.9	114.1	124.7	142.0	139.9	160.4	186.8	212.3
250-bushel*	101.5	115.3	125.6	143.8	141.2	163.1	188.8	216.1
350-bushel*	102.0	116.4	126.4	145.5	142.4	165.5	190.5	219.6
450-bushel*	---	---	127.3	147.3	143.7	168.2	192.4	223.4
550-bushel*	---	---	128.7	149.9	145.6	172.0	195.2	228.9
2 350-bushel*	---	---	129.4	151.4	146.7	174.0	196.6	231.9
2 450-bushel*	---	---	---	---	149.3	179.3	200.4	239.5

*Assumes 50 percent of travel is loaded and 50 percent of travel is unloaded.

The type of equipment pulled by the tractor on paved surfaces had little impact on the variable cost per mile. Variable costs increased only two percent for a small tractor pulling a 350-bushel wagon compared to driving the tractor alone. For the large 185 h.p. tractor, variable costs increased only 8.7 percent when pulling two 450-bushel wagons. The impact of the type of equipment pulled on variable cost per mile was slightly higher on gravel surfaces than on paved surfaces. Variable costs per mile for the smallest tractor and for the largest tractor when pulling two large wagons increased 3.3 and 15 percent, respectively, over the cost of driving the tractor alone.

Variable cost increases on gravel surfaces over paved surfaces were smaller for tractors than for road vehicles. Variable cost increases for tractors on gravel surfaces ranged from 12 to 14 percent for the 60 h.p. tractor, 13 to 17 percent for the 100 h.p. tractor, 14 to 20 percent for the 140 h.p. tractor, and 12 to 20 percent for the 185 h.p. tractor. The smaller increases for travel on gravel surfaces were a result of tractors being designed to operate on low quality surfaces. For example, tractor tires have less wear on gravel roads than on paved roads.

Table 14 presents the estimated variable running costs in cents per mile for farm combines. The variable cost of operating a small two-row combine on a paved road was 101.7 cents per mile; this cost increased 12 percent on a gravel road. The cost per mile increased sharply with larger size combines. On paved surfaces, the cost per

mile of a 6-8 row combine was 59 percent higher than for a two-row combine; on gravel surfaces, the 6-8 row combine cost was 60 percent more per mile than for a 2-row combine.

Table 14. Estimated 1982 farm combine variable cost in cents per mile on paved and gravel surfaces by size of combine.

Engine horsepower	Size of corn head	Cost per mile	
		Paved	Gravel
70	2	101.69	114.70
120	4	146.13	164.85
145	6-8	161.70	183.22

Post Office Travel Costs

All postal travel costs were provided by the United States Postal Service. Postal travel cost per mile for 1982 included a 30-cent per mile vehicle allowance. Carrier salary costs, including fringe benefits, were estimated to be $900 per hour per year. The average speed for postal carriers was estimated to be 12 miles per hour.

Travel Time Penalty

For the time-critical farm operations, an extra cost was added to the increased travel cost due to changes in the road system. A travel time penalty is incurred if the increased travel prohibits a farmer from completing time-critical operations, such as planting or harvesting, in the same amount of time as before the change in the road system. In this study, the travel time penalty was charged only to the

increase in time-critical farm operations resulting from reductions in the miles of road. The method used to estimate this cost was to calculate the cost of increasing the farmer's machine capacity to allow the farmer to drive the additional distance and complete the time-critical operations on the same number of acres in the same amount of time required before the change in the road system. Appendix D presents a detailed explanation of the travel time penalty and the estimation procedure.

The estimated travel time penalty costs, presented in Table 15, were applied only to the increased planter, combine and part of the tillage road travel miles resulting from changes in the road system.

Table 15. Travel time penalty vehicle costs applied to the increased travel due to a change in the road system by type of vehicle in cents per mile.

Machine	Road surface	
	Paved	Gravel
Planter/tillage	372	413
Combines		
2-row	83	99
4-row	229	247
6-8 row	436	479

Opportunity Cost of Using Land for Roads

Land used for roads incurs an opportunity cost because there are other productive uses of that land, and that opportunity cost must be

considered in the benefit-cost ratio. Agricultural production is the most likely alternative use for the land in the three study areas. Rental values were used as the measure of the opportunity cost of keeping the land in roads.

Farmland rental values in 1982 for Hamilton, Shelby, and Linn Counties were estimated in two steps. First, the crop reporting district average rental rate per acre was calculated as a percent of the average land value in the crop reporting district. To obtain the estimated county land rent, the 1982 average county farmland value was multiplied by the percent that the average crop reporting district rental rates were of farmland value. Table 16 presents the estimated 1982 rental values for the three study areas.

Table 16. Estimated rental values of farmland per acre in the three study areas, 1982.

Study area	1982 land rental value per acre
Hamilton	$140.91
Shelby	95.49
Linn	126.74

CHAPTER V

RESULTS

The main purposes of this study are to evaluate the economic benefits and costs of reducing the number of miles of county roads in three study areas in Iowa and to determine the incidence of these benefits and costs. The benefits and costs of reducing the number of county roads were estimated by removing selected roads from the computerized road network and rerunning a computer program which simulates the effects of the smaller road system on travel miles and costs. The only roads eliminated from the Linn and Shelby County study areas were those roads that serve no property or residence accesses. In the Hamilton study area, roads with no property or residence accesses were first eliminated from the computerized county road system. However, removing the first set of roads from the computerized Hamilton study area road network created several dead-end roads in the network. Dead-end roads are road segments that connect with another road at only one end of the segment. Therefore, in the second Hamilton study area solution, these dead-end roads were converted from public roads to private drives in the computerized county road network. Only traffic originating or terminating on the private drives was permitted to travel over the private drives. In addition, a small number of low traffic volume roads that were not dead-end roads that serve field and household accesses were also converted to private drives.

Road Selection Criteria and Study Assumptions

The criteria for selecting roads to be eliminated from the computerized road networks were as follows:

I. Roads which landlocked no property or houses were eliminated from the system. This category of roads had three common characteristics.

   a. road surface--only gravel or earth surfaced roads were eliminated from the networks.

   b. traffic levels--roads with low traffic levels were eliminated.

   c. traffic flows--only roads which do not serve as an important link in the network were eliminated from the network.

II. Roads which landlock property or houses were converted to private drives under the following criteria:

   a. traffic levels--only roads with low traffic levels were converted to private drives.

   b. dead-end roads--roads which became or were already dead-end roads were converted to private drives.

The following assumptions were made in this analysis:

* The traveling public attempts to minimize the travel costs from an origin to a destination.
* The number of trips from an origin to a destination does not change as a result of changes in the road system.

* The routes used to travel from an origin to a destination can change if the road system changes.
* The variable vehicle travel costs are a linear function of distance.
* The U.S. Postal Service must serve all residences that have a passable road access.
* School buses must provide school transportation to all residences with school-age children.
* If the variable maintenance cost on the existing surface of a paved road exceeds the annualized cost of resurfacing to a higher quality pavement, the road will be upgraded to a higher quality surface.
* A portion of the road maintenance costs are independent of traffic levels. The remaining maintenance costs vary with traffic levels.

A network algorithm was used to determine the cost minimizing routes and distances with all 1982 county roads in the model for all 1982 trips from each origin to each destination for each farm and household in each study area. This computer run is called the base solution. Then, specific road segments were removed from the computerized road network, and the computer model was rerun to reroute the same trips from each origin to each destination for each vehicle type. With a smaller number of road miles, the total travel miles increased because of longer distances between some origins and destinations. The difference between the total travel cost of the computer solution with

a smaller road system and the total travel cost of the base solution is the estimated savings in travel cost by the traveling public if all base solution roads remain open. The cost to the counties or the public to keep the roads open include the differences in fixed and variable maintenance costs between the two solutions, and in the annualized periodic resurfacing and reconstruction costs. In addition, the opportunity cost of keeping the land in roads rather than in agricultural production was included in the cost of keeping the roads open.

The estimated savings to the traveling public and the cost of keeping the analyzed roads open were used to calculate benefit-cost ratios for each group of roads. If the benefit-cost ratio is greater than 1.0, the benefits to the traveling public exceed the cost to the public of keeping the group of roads in the system. If the benefit-cost ratio is less than 1.0, the public cost of keeping the roads in the system exceeds the travel cost savings to the traveling public. The following are the results of the analysis in each of the three study areas.

Linn County Study Area

Table 17 presents the estimated miles of travel in the Linn County study area under two solutions. The first solution, the base solution, had all the study area roads in the computer road network. The second solution, called L_1, had nine miles of study area roads removed from the computerized road network. The nine miles of road, consisting of five miles of gravel road and four miles of earth surfaced road, served no household, farm or field accesses. In addition, three bridges with

Table 17. Estimated total miles driven in the Linn County study area under the base and L_1 solutions by vehicle groups, 1982.

Type of travel	Base solution				L_1 solution				Change from base to L_1			
	Miles		Percent of total		Miles		Percent of total		Miles		Percent of total	
Household:												
Auto	18,070,652		64.2		18,189,437		64.2		118,785		60.8	
Pickup	1,046,123		3.7		1,050,148		3.7		4,025		2.1	
Trucks	499,378		1.8		500,180		1.8		802		0.4	
Subtotal		19,616,153		69.7		19,739,765		69.6		123,612		63.2
Overhead traffic		7,045,511		25.0		7,045,511		24.8		0		0
Farm:												
Auto	33,217		0.1		34,411		0.1		1,194		0.6	
Pickup	969,429		3.4		1,010,912		3.6		41,483		21.2	
Trucks	203,644		0.7		205,269		0.7		1,625		0.8	
Tractor - wagons	21,146		0.1		22,672		0.1		1,526		0.8	
Tractor pulling equipment or alone	98,876		0.4		107,038		0.4		8,162		4.2	
Combines	8,672		0.0		9,171		0.0		499		0.3	
Subtotal		1,334,984		4.7		1,389,473		4.9		54,489		27.9
Other:												
School buses	88,110		0.3		102,150		0.4		14,040		7.2	
Post office	71,100	159,210	0.3	0.6	74,448	176,598	0.3	0.7	3,348	17,388	1.7	8.9
Grand total		28,155,858		100.0		28,351,347		100.0		195,489		100.0

a total of 2,335 square feet of deck space were eliminated. Map 2 shows the Linn study area road system in the base solution and the abandoned roads in the L_1 solution.

The estimated vehicle miles driven in the study area in the 1982 base solution totaled 28.1 million miles. Of this total, 19.6 million or 69.7 percent of total miles were driven for household purposes; most of this travel was in automobiles.

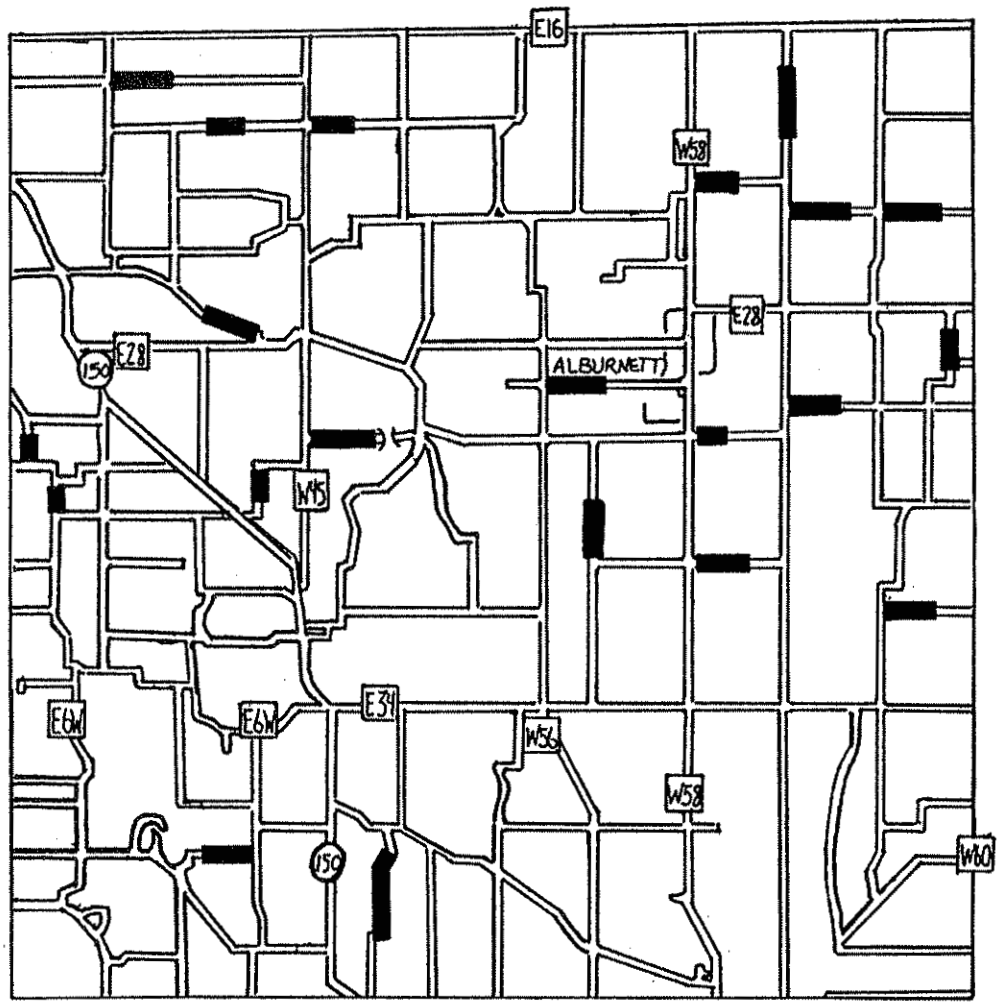
Over seven million miles or one-fourth of all travel was overhead traffic. Overhead traffic is defined as that traffic traveling through, but not originating or terminating in, the study area.

The third important category of traffic was farm travel. Farm travel included automobile and pickup truck miles driven for farm purposes as well as larger farmer-owned trucks, commercial trucks serving the farm operation and all farm implement miles. Farm travel totaled 1.3 million miles or 4.7 percent of all traffic in the Linn County study area. Farm pickup truck travel was 3.4 percent of all travel and almost 73 percent of all farm travel. The next largest type of farm travel was truck miles. Truck miles include farmer-owned trucks and trucks serving farms but owned by farm supply and marketing firms.

The fourth category of travel in the study area was school bus and postal service miles. These two types of travel each represented 0.3 percent of total 1982 travel in the study area.

After removing the nine miles of road serving no household, farm or field accesses in the L_1 solution, total travel miles increased by about 0.6 percent over the base solution miles. Household traffic

Map 2. Linn County Study Area



L1—Roads examined for abandonment
9.0 miles; 3 bridges

increased by 0.6 percent or about the same percent as total traffic; most of the increase in household travel miles was by automobiles.

None of the overhead traffic traveled on the nine miles of road removed from the base solution road network. Therefore, eliminating the nine miles of road resulted in no change in overhead traffic miles.

Farm vehicle traffic increased about 4.1 percent from the abandonment of the nine miles of road. Pickup trucks accounted for over 75 percent of this increased farm vehicle traffic. Tractors accounted for 15 percent of the increased farm miles, and larger trucks accounted for only three percent of the increased farm traffic.

School bus and postal vehicle miles increased 10.9 percent; this was the largest percent increase in travel of all the vehicle groups. This is reasonable because these vehicles must provide service to the same households under both road systems. Postal service miles increased 4.7 percent which is well above the percent increase in total miles driven.

Table 18 presents the estimated total variable cost of travel in the base and L_1 solutions. Under the base solution with all study area roads in the computerized network, the estimated total variable cost of all travel in the study area was $6.9 million. About two-thirds of the total variable cost was for household travel, mostly by automobile. Overhead travel cost was about one-fourth of all travel cost. Farm vehicle travel costs were eight percent of all vehicle travel costs even though the farm vehicle had only four percent of

Table 18. Estimated total variable cost of all travel in the Linn County study area under the base and L_1 solutions, by vehicle groups, 1982.

Type of travel	Base solution				L_1 solution				Change from base to L_1			
	Cost		Percent of total		Cost		Percent of total		Cost		Percent of total	
Household:												
Auto	$3,901,648		56.9		$3,920,846		56.7		$19,198		34.1	
Pickup	277,969		4.1		278,822		4.0		853		1.5	
Trucks	342,118		5.0		342,221		5.0		103		0.2	
Subtotal		$4,521,735		66.0		$4,541,889		65.7		$20,154		35.8
Overhead traffic		1,688,245		24.6		1,688,245		24.4		0		0
Farm:												
Auto	$ 7,847		0.1		$ 8,021		0.1		$ 174		0.3	
Pickup	281,916		4.1		292,793		4.2		10,877		19.3	
Trucks	83,655		1.2		84,330		1.2		675		1.2	
Tractor - wagons	29,787		0.5		31,739		0.5		1,952		3.5	
Tractor pulling equipment or alone	128,327		1.9		138,662		2.0		10,335		18.4	
Combines	13,856		0.2		14,549		0.2		693		1.2	
Timeliness	0		0		3,231		0.1		3,231		5.8	
Subtotal		545,388		8.0		573,325		8.3		27,937		49.7
Other:												
School buses	$ 35,583		0.5		$ 40,680		0.6		$ 5,097		9.1	
Post office	63,707	99,290	0.9	1.4	66,743	107,423	1.0	1.6	3,036	8,133	5.4	14.5
Grand total		$6,854,658		100.0		$6,910,882		100.0		$56,224		100.0

total miles. Combined school bus and postal service travel costs were 1.4 percent of total cost, but only one-half of one percent of the total miles of travel. The reason for the high farm, school bus and postal vehicle share of total cost relative to total miles driven is the high cost per mile of driving these vehicles.

After the nine miles of road were eliminated from the computerized road network in the L_1 solution, total travel cost increased $56,224 or an increase of 0.8 percent over the base solution cost. Almost half of the increased cost was for farm travel, even though farm travel miles had only 27.9 percent of the change in miles driven. The $27,937 of increased farm travel costs represents the value of the nine miles of road to agriculture. The higher farm share of total cost is caused by the high travel cost per mile of farm vehicles. In addition, a travel time penalty of $3,231 was charged for the time of the planter/tillage equipment and combine lost field time because of the longer travel distances. The travel time penalty charge is equivalent to the additional investment in farm equipment required to enable the farmer to plant and harvest his crops in the same total time, including travel time, as the total time required in the base solution. Household travel had 35.8 percent of the change in total cost, but this group had 63 percent of the change in miles driven. School buses and post office vehicles had 9.1 percent and 5.4 percent of the change in total travel costs, respectively.

Table 19 presents the annual cost to the county to maintain the L_1 (nine) miles of road. Less than 10 percent of the total cost

Table 19. Estimated total annual cost of keeping the nine miles of L_1 roads in the Linn County road system, 1982.

Type of cost		Annual cost
Cost to the county		
Variable road maintenance		$ 2,460
Fixed road maintenance		20,729
Resurfacing		1,585
Reconstruction		5,723
Bridge maintenance		1,868
Total county cost		$32,365
Plus		
Rental value foregone if land is used as roads	$9,125	
Less		
Road obliteration costs	504	8,621
Total cost of keeping the L_1 roads		$40,986

to the county of $32,365 were costs that vary with traffic levels. The remainder of the costs are largely independent of traffic levels. In addition to the county costs, keeping the land in roads results in an opportunity cost to the abutting land owners because, in most cases, if a county road is abandoned, the land reverts to the abutting land owners, who can return the land to agricultural production or other productive uses. Using 1982 land rental values for agricultural purposes, the estimated rental value for the land in the nine miles of road was $9,125. However, a cost of $1,000 per mile was charged to obliterate the road and convert the road bed to agricultural production. The

annualized cost of obliterating the nine miles of road was $504, resulting in a net rental value of $8,621. The gross rental value would accrue to the abutting land owners. In most cases, the county would incur the obliteration costs.

Table 20 summarizes the results of the analysis of the nine miles of Linn County roads. The benefit-cost ratio for keeping the nine miles of road and three bridges in the system was 1.37. This means that the traveling public would save $1.37 in travel costs for every $1.00 spent in keeping the nine miles of roads in network.

Table 20. Benefit-cost results of the Linn County study area analysis.

Benefits to the traveling public from keeping the L_1 miles of road in the system	$56,224
Costs of keeping the nine miles of road in the network	40,986
Benefit-cost ratio	1.37
Change in:	
a. miles of road	-9
b. number of bridges	-3

The benefit-cost ratio is an average over 21 sections of road totaling nine miles which serve no residence, farm or property accesses. The average daily traffic on the L_1 road segments was 21 vehicles per day. However, eight of the road segments had less than 10 vehicles per day. The benefits to the traveling public for keeping the

roads in the network depend on the number and type and cost of the vehicles traveling over the roads under analysis, as well as the additional travel distance required if the roads are removed from the network. Obviously, a very small number of vehicles per day means low travel savings from keeping the roads in the network. Thus, the conclusion from the Linn County study area analysis is that, on the average, keeping the nine miles of analyzed roads in road system will return benefits to the traveling public greater than the cost of keeping the roads. Nevertheless, there is a small group of roads in this nine miles that will likely save the traveling public fewer dollars than the cost of keeping these roads. Thus, some roads with very low vehicle traffic levels could still be candidates for abandonment. Individual analysis of these low traffic roads would be needed to determine benefits to the traveling public and the cost of keeping these roads in the system. The basic conclusion from the Linn study area analysis is that there is limited potential cost savings from reducing the size of the county road system in urbanized areas like the study area in Linn County.

Shelby County Study Area

Table 21 presents the estimated miles of travel in the Shelby County study area under four solutions. The first solution, called the base solution, had all the study area roads in the computer network. The first alternative solution, called S_1, had 9.25 miles of study area roads removed from the computerized network. The second solution,

Table 21. Estimated total miles driven in the base solution and change in miles driven in each of three solutions with reduced miles of road, by vehicle group, Shelby County study area, 1982.

Type of travel	Base solution				Change in miles driven from previous solution											
					S_1 (9.25 miles)				S_2 (6.75 miles)				S_3 (5.25 miles)			
	Miles		Percent of total		Miles		Percent of total		Miles		Percent of total		Miles		Percent of total	
Household:																
Auto	3,657,386		58.9		27,218		36.9		38,767		25.1		103,134		47.0	
Pickup	464,614		7.5		1,117		1.5		2,549		1.6		6,944		3.1	
Trucks	123,192		2.0		762		1.0		405		0.3		3,232		1.5	
Subtotal		4,245,192		68.4		29,097		39.4		41,721		27.0		113,310		51.6
Farm:																
Auto	34,369		0.6		630		0.9		3,123		2.0		996		0.4	
Pickup	1,449,380		23.4		22,519		30.5		70,612		45.8		78,751		35.9	
Trucks	179,620		2.9		1,114		1.5		2,283		1.5		3,510		1.6	
Tractor - wagons	42,353		0.7		479		0.6		2,398		1.6		2,370		1.1	
Tractor pulling equipment or alone	126,652		2.0		15,564		21.1		19,953		12.9		7,692		3.5	
Combines	8,491		0.1		700		0.9		881		0.6		704		0.3	
Subtotal		1,840,865		29.7		41,006		55.5		99,250		64.4		94,023		42.8
Other:																
School buses	52,024		0.8		2,250		3.1		8,640		5.6		6,930		3.2	
Post office	65,383	117,407	1.1	1.9	1,495	3,745	2.0	5.1	4,636	13,276	3.0	8.6	5,194	12,124	2.4	5.6
Grand total		6,203,464		100.0		73,848		100.0		154,247		100.0		219,457		100.0

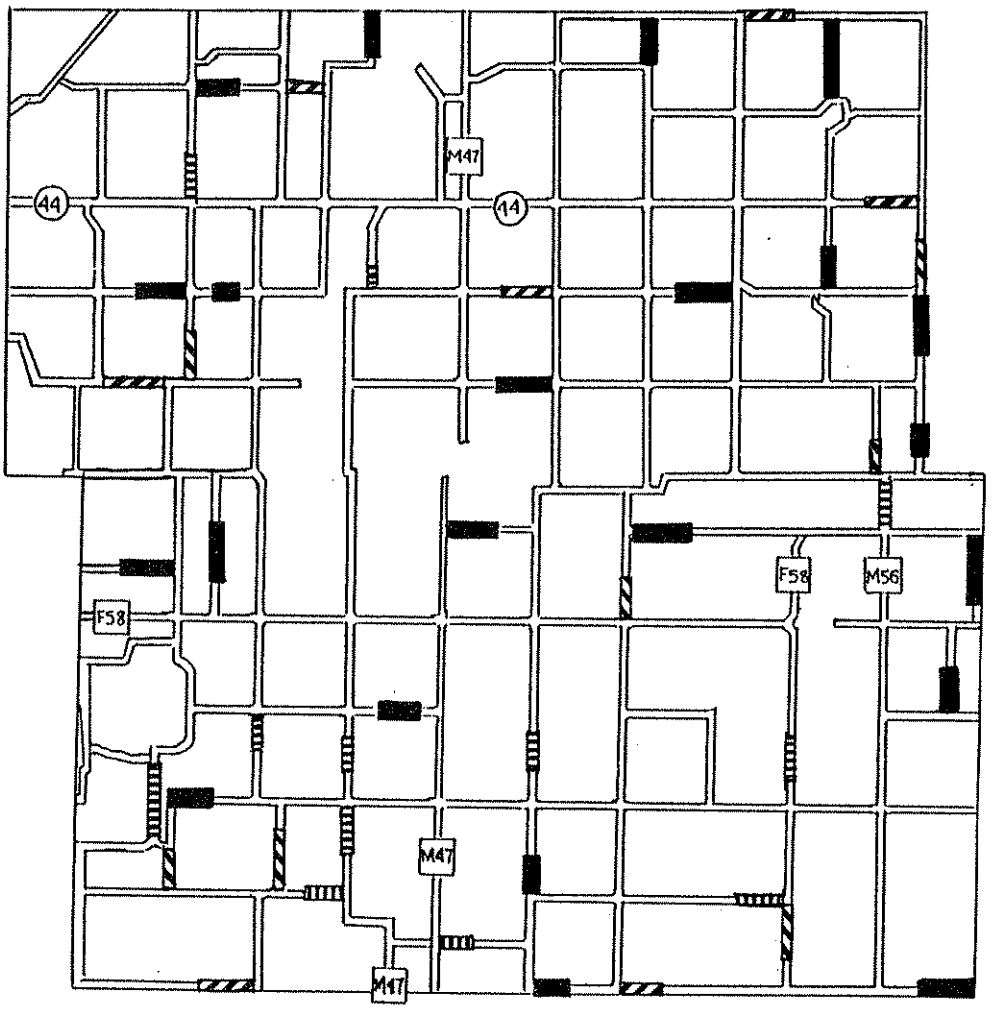
called S_2, had 6.75 miles of road removed from the network. The third alternative solution, called S_3, had 5.25 miles of road removed from the network. None of the S_1, S_2 or S_3 roads served household, farm, or field accesses. In addition, 11 bridges with a total of 12,699 square feet of deck space were eliminated in S_1, and one bridge each was eliminated in the S_2 and S_3 solutions. Table 22 shows number of miles of road abandoned in each of the Shelby study area solutions by type of road system. All of the abandoned roads were gravel, oil or earth surfaced. Map 3 shows the roads in the base solution and the roads abandoned in the S_1, S_2 and S_3 solutions.

Table 22. Miles of road in the base solution and miles abandoned in Shelby County by surface type and computer solution.

Surface type	Base solution	Miles of road abandoned in		
		S_1	S_2	S_3
Paved	23.5	0	0	0
Gravel	75.0	1.5	3.5	4.0
Oiled	74.2	1.5	1.0	1.25
Earth	31.7	6.25	2.25	0
Total	204.4	9.25	6.75	5.25

From Table 21, the estimated vehicle miles driven in the study area in 1982 totaled 6.2 million miles. The Shelby study area had only 22 percent as many traffic miles as the Linn study area. Of this total, 4.2 million or 68.4 percent of total miles were driven for household purposes; most of this travel was in automobiles.

Map 3. Shelby County Study Area



S1—Roads examined for abandonment
Average daily traffic mostly less than 10 vehicles
9.25 miles; 11 bridges

S2—Roads examined for abandonment
Average daily traffic mostly 11 to 30 vehicles
6.75 miles; 1 bridge

S3—Roads examined for abandonment
Average daily traffic greater than 30 vehicles
5.75 miles; 1 bridge

Total miles = 21.75

Farm travel totaled 1.8 million miles or 29.7 percent of all traffic in the Shelby County study area. Farm pickup truck travel was 23.4 percent of all travel and almost 79 percent of all farm travel. The next largest type of farm travel was large truck miles which totaled only 2.9 percent of total miles.

The third category of travel in the study area was school bus and postal service miles. These two types of travel each represented 1.9 percent of total 1982 travel in the study area.

After removing the 9.25 miles of road, total travel miles in the S_1 solution increased by about 1.2 percent over the base solution miles. Household traffic increased by only 0.7 percent or just slightly more than half as much as total traffic miles. Most of the increased household traffic was by automobiles.

Farm vehicle traffic increased about 2.2 percent due to the abandonment of the 9.25 miles of road. Pickup trucks accounted for over 55 percent of this increased farm vehicle traffic. Tractors accounted for 39 percent of the increased farm traffic, and large trucks accounted for only 2.7 percent of the increased farm traffic.

School bus miles increased 4.3 percent. Postal service miles increased 2.3 percent, which is almost double the percent increase in total miles driven.

There was a larger increase in total miles driven in the S_2 solution than in S_1, even though fewer miles of road were abandoned in the S_2 solution. Overall, total miles driven increased 2.5 percent in the S_2 solution over the combined S_1 and base solutions.

The largest increase in miles driven in S_2 was by farm pickup trucks, followed by household automobiles and farm tractors. Almost half of the S_2 increase in miles was by farm pickups and 25 percent was by household automobiles.

The S_3 solution created a larger increase in total miles driven than the S_1 or S_2 solution, even though S_3 had only 5.25 miles of road abandoned. Total miles driven in S_3 increased 3.4 percent over the combined base, S_1 and S_2 solution miles. Almost half of the S_3 increase in miles was by automobiles driven for household purposes, while pickup trucks had a 35.9 percent increase in miles driven. The major reason for the large increase in automobile and pickup miles in S_3 is that most of the roads abandoned in S_3 had relatively high traffic levels and were relatively close together which reduced the rerouting options. The geographic concentration of the abandoned roads in S_3, combined with roads abandoned in S_2 and S_1 which were nearby, resulted in long travel distances for automobile and pickup traffic to get into and out of the area.

Table 23 presents the estimated total variable cost of travel in the Shelby base solution and the change in the total cost of travel for the S_1, S_2 and S_3 solutions. Under the base solution with all study area roads in the computerized network, the estimated total variable cost of all travel in the study area was $1.85 million. Fifty-five percent of the total variable cost was for household travel, mostly by automobile. Farm vehicle travel costs were 40.6 percent of all vehicle travel costs, even though the farm vehicles had only 29.7

Table 23. Estimated total cost of all travel in the base solution and change in total cost in each of three solutions with reduced miles of road, by vehicle group, Shelby County study area, 1982.

					Change in total variable cost from the previous solution											
	Base solution				S_1 (9.25 miles)				S_2 (6.75 miles)				S_3 (5.25 miles)			
Type of travel	Cost		Percent of total		Cost		Percent of total		Cost		Percent of total		Cost		Percent of total	
Household:																
Auto	$832,791		44.9		$ 5,219		13.3		$10,976		14.0		$27,136		35.2	
Pickup	127,411		6.9		224		0.6		951		1.2		2,018		2.6	
Trucks	59,246		3.2		222		0.5		343		0.4		1,612		2.1	
Subtotal		$1,019,448		55.0		$ 5,665		14.4		$12,270		15.6		$30,766		39.9
Farm:																
Auto	$ 9,024		0.5		$ 185		0.5		$ 886		1.1		$ 276		0.4	
Pickup	433,302		23.4		6,940		17.7		22,234		28.4		25,133		32.6	
Trucks	72,185		3.9		298		0.7		853		1.1		1,647		2.1	
Tractor - wagons	56,691		3.0		617		1.6		3,217		4.1		3,258		4.2	
Tractor pulling equipment (or alone)	168,495		9.1		19,888		50.6		26,079		33.2		3,562		4.6	
Combines	13,590		0.7		1,099		2.8		1,415		1.8		1,154		1.5	
Timeliness	0		0.0		2,192		5.6		3,379		4.3		3,598		4.7	
Subtotal		753,287		40.6		31,219		79.5		58,063		74.0		38,628		50.1
Other:																
School buses	$22,537		1.2		$ 1,051		2.7		$ 3,950		5.1		$ 3,004		3.9	
Post office	58,584	81,121	3.2	4.4	1,340	2,391	3.4	6.1	4,154	8,104	5.3	10.4	4,654	7,658	6.1	10.0
Grand total		$1,853,856		100.0		$39,275		100.0		$78,437		100.0		$77,052		100.0

percent of total miles. The combined school bus and postal service travel cost was 4.4 percent of total cost, but these two types of vehicles had only 1.9 percent of the total miles of travel. The reason for the high farm, school bus and postal share of total cost relative to total miles driven is the high cost per mile of driving these vehicles.

After the 9.25 miles of road were eliminated from the computerized road network in the S_1 solution, total travel cost increased $39,275, or an increase of 2.1 percent over the base solution cost. Almost 80 percent of the increase in cost was for farm travel even though farm travel miles had only 55.5 percent of the change in miles driven. The $31,219 increase in farm travel costs is the value of the 9.25 miles of S_1 roads to agriculture.

In the S_2 solution, total travel cost increased $78,437, an increase of 4.1 percent over the combined base and S_1 solutions. Almost 75 percent of the increased travel cost was for farm travel.

In the S_3 solution, total travel costs increased $77,052, an increase of 3.9 percent over the combined base, S_1 and S_2 solution costs. About 40 percent of that increased travel cost was for household travel, 50 percent for farm travel and 10 percent for school bus and post office travel.

Table 24 presents the annual cost of maintaining the roads eliminated from the S_1, S_2 and S_3 solutions. Total variable maintenance costs do not fall if the S_1, S_2 and S_3 roads are removed from the system. The reason is that the traffic traveling on these

Table 24. Estimated total annual cost of keeping the S_1, S_2 and S_3 roads in the Shelby County road system.

Type of cost	Annual cost		
	S_1	S_2	S_3
Cost to the county			
Variable road maintenance	$ -944	$-2,676	$-4,719
Fixed road maintenance	20,957	17,001	14,517
Resurfacing	811	765	-1,869
Reconstruction	9,906	4,572	- 23
Bridge maintenance	10,159	2,743	$ 1,568
Total cost to the county	$40,889	$22,405	$ 9,474
Plus			
Rental value foregone if land is used as roads	7,066	5,156	4,011
Less			
Road obliteration costs	4,403	3,213	2,499
Total cost of keeping the roads	$43,552	$24,348	$10,986

roads in the base solution was rerouted to other roads in the S_1, S_2 and S_3 solutions. Most of the roads in the Shelby study area are unpaved, and most of the rerouted traffic continued to move over unpaved roads. Unpaved roads have higher variable maintenance costs than paved roads. Thus, when the S_1, S_2 and S_3 roads were removed from the computerized road networks, the higher traffic levels over the remaining unpaved roads resulted in higher total variable maintenance costs than if all the roads remained in the system.

Fixed road maintenance costs declined sharply in the S_1, S_2 and S_3 solutions because the reduced miles of road reduced the amount of fixed road maintenance costs.

Resurfacing and reconstruction costs declined as the number of miles of road declined in the S_1 and S_2 solutions. However, increased resurfacing and reconstruction costs on the remaining roads in the S_3 solution more than offset the resurfacing and reconstruction cost reductions on the roads abandoned in the S_3 solution. The main reason for the relatively small resurfacing savings in the S_1 and S_2 solutions and the resurfacing and reconstruction cost increase in the S_3 solution is that the poor quality roads remaining in the Shelby study area required additional resurfacing and reconstruction as they inherited additional traffic.

Bridge maintenance costs changed with the number of square feet of deck space of bridges in the S_1, S_2 and S_3 solutions. The S_1 solution eliminated 12,699 square feet of bridge deck space, S_2 eliminated 3,428 square feet of bridges and S_3 eliminated 1,960 square feet of bridge deck space.

Each mile of road contains eight acres of land. Thus, the abandoned S_1 roads contained 74 acres of land, the abandoned S_2 roads contained 54 acres of land, and the abandoned S_3 roads contained 42 acres of land. The 1982 rental value of land in Shelby County was estimated to be $95.49 per acre. However, the estimated cost of obliterating the roads and returning the land to agricultural production was estimated to be $8,500 per mile. The net result of all

the costs of maintaining these roads was \$43,552 for the S_1 roads, \$24,348 for the S_2 roads and \$10,986 for the S_3 roads.

Table 25 summarizes the results of the analysis of the S_1, S_2, and S_3 solutions. The benefit-cost ratio for the S_1 roads was 0.90. This means that the traveling public receives \$0.90 in travel cost savings for each \$1.00 spent on keeping the S_1 roads in the system. The benefit-cost ratios for the S_2 and S_3 roads were 3.22 and 7.01, respectively. These benefit-cost ratios are averages over many sections of road. As shown in Table 26, there was a wide range in the average number of vehicles per day on these road segments. In the S_1 solution, 78 percent of the road segments had 10 or fewer vehicles per day. In S_2, 43 percent of the roads had 21-30 vehicles per day. In the S_3 solution, 54 percent of the roads had 31-40 vehicles per day. Benefits to the traveling public for keeping individual roads in the network depend on the number, type and cost of the vehicles traveling over the roads as well as the additional travel distance required if the roads are removed from the network. Obviously, a very small number of vehicles per day means low travel savings from keeping the roads in the network. Thus, the conclusion from the Shelby County study area analysis is that, on the average, keeping the roads in S_1 return benefits to the traveling public that are slightly lower than the cost of keeping these roads. Keeping the roads in S_2 and S_3 would return benefits to the traveling public greater than the cost of keeping the roads.

There are small groups of roads in the S_1 and S_2 solutions that, if abandoned, would likely cost the traveling public fewer

Table 25. Benefit-cost ratios in Shelby County study area by computer solution.

Benefit-cost component	S_1	S_2	S_3
Benefits to the traveling public from keeping the S_1, S_2 and S_3 roads in the system	$39,275	$78,437	$77,052
Costs of keeping the S_1, S_2 and S_3 roads in the system	43,552	24,348	10,986
Benefit cost ratio	0.90	3.22	7.01
Change in:			
a. miles of roads	-9.75	-6.75	-5.25
b. number of bridges	-11	-1	-1

Table 26. Average number of base solution vehicles per day traveling over the Shelby study area roads abandoned in the S_1, S_2 and S_3 solutions.

Average number of vehicles per day	Number of roads abandoned		
	S_1	S_2	S_3
0-10	21	3	0
11-20	6	5	0
21-30	0	6	2
31-40	0	0	7
41-50	0	0	4
Over 50	0	0	0

dollars than the cost of keeping these roads. Thus, a second conclusion is that an analysis of individual roads is needed to determine which individual roads save the traveling public less than the cost of keeping each road in the system.

A third but tentative conclusion can be drawn from the Shelby analysis about the strategy of reducing the number of county roads to save costs. Reducing the miles of road in an area where the remaining roads are of poor quality is likely to increase travel costs more than the cost savings from road abandonment. Only 11 percent of the roads in the Shelby County study area are paved. Thus, most of the rerouted traffic after a road abandonment was necessarily routed over unpaved roads. Both vehicle travel costs and road maintenance costs are higher on unpaved than on paved roads. The higher vehicle travel costs increased the numerator of the benefit-cost ratio. The high maintenance costs on unpaved or low quality paved roads reduced the denominator when these roads inheriteded additional traffic. These high travel and maintenance costs were a major reason for the high benefit-cost ratios in Shelby County. The benefit-cost ratio for the S_1 solution might have been substantially below one, and the benefit-cost ratio for the S_2 solution may have been below one if there had been a core system of properly spaced paved roads in the Shelby study area.

Hamilton County Study Area

Three computer solutions were run for the Hamilton County study area. The base solution included all roads in the study area in 1982.

The first alternative solution, H_1, estimated total miles driven and travel costs after 17.75 miles of gravel road were removed from the Hamilton County study area network. None of the roads removed from the H_1 solution served field, farm or residence accesses.

In the second alternative solution, H_2, 40 additional miles of gravel road were removed from the computerized road network and converted to private drives. The transfer of these public roads to private roads was based on the assumption that originating or terminating traffic could travel over the private drives and that the maintenance costs of the H_2 miles would shift from the county to the abutting land owners.

Three miles of road in the H_2 solution were different from the remaining 37 miles of road. The three miles of the H_2 roads served property accesses but no household accesses and were connected at both ends to other roads so that overhead traffic had traveled on these roads. Converting these three miles of roads to private drives resulted in rerouting of overhead traffic. The remaining 37 miles of H_2 roads served property and residence accesses, but all were dead-end roads. They had been dead-end or became dead-end roads because of abandonment of the 17.75 miles of roads in H_1 and converting the three miles of non-dead-end roads in H_2 to private drives. The dead-end roads served only traffic originating or terminating on the dead-ends. Therefore, converting these roads to private drives caused no

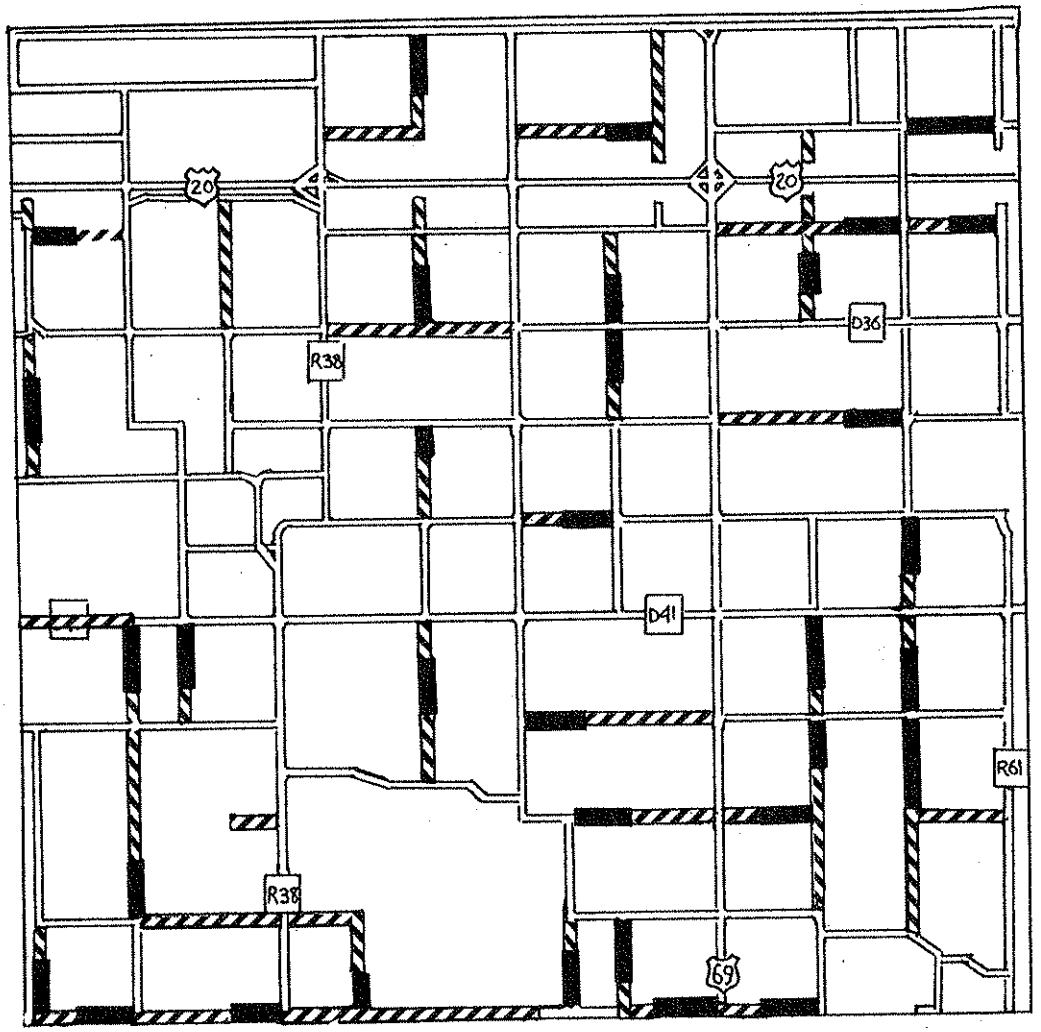
traffic to be rerouted and caused no additional travel costs. Map 4 shows the roads in the base solution, the roads abandoned in the H_1 solution and the roads converted to private drives in the H_2 solution.

Table 27 presents the estimated total miles driven in the Hamilton base solution and the additional miles driven by rerouted traffic in the H_1 and H_2 solutions. Vehicle miles driven in the Hamilton study area base solution totaled just over 5 million. Almost two-thirds of these miles were driven for household purposes; mostly in automobiles. Almost 35 percent of the miles driven were for farm purposes; over 77 percent of the farm related miles was by pickup trucks. Only two percent of all traffic was school bus or postal service miles.

After the 17.75 miles of gravel road were removed in the H_1 solution, total distance traveled increased 121,286 miles, an increase of 2.4 percent over the base solution miles. Two-thirds of the increased miles were for farm purposes, largely by pickup trucks. Only 35 percent of the base solution miles were for farm purposes. Post office and school bus miles had only two percent of the base solution miles but had over 16 percent of the additional miles in the H_1 solution. Household travel had 63 percent of the base solution miles but had less than 18 percent of the additional miles resulting from the abandonment of the 17.75 miles of H_1 roads.

In the H_2 solution, total traffic increased 71,542 miles, an increase of 1.4 percent over the combined base and H_1 solution miles.

Map 4. Hamilton County Study Area



H1—Roads examined for abandonment
17.75 miles; 5 bridges

H2—Roads examined for conversion to private drives
40.0 miles; 9 bridges

Table 27. Estimated total miles driven in the base solution and change in miles driven in two solutions with reduced miles of road, by vehicle groups, Hamilton County study area, 1982.

Type of travel	Base solution				H_1 (17.75 miles)				H_2 (40 miles)			
	Miles		Percent of total		Miles		Percent of total		Miles		Percent of total	
Household:												
Auto	2,966,625		59.2		19,510		16.1		13,778		19.3	
Pickup	132,335		2.7		261		0.2		728		1.0	
Trucks	59,090		1.2		1,627		1.3		580		0.8	
Subtotal		3,158,050		63.1		21,398		17.6		15,086		21.1
Farm:												
Auto	52,731		1.0		5,116		4.2		1,956		2.7	
Pickup	1,352,440		27.0		53,157		43.8		36,072		50.4	
Trucks	133,842		2.7		8,021		6.6		803		1.2	
Tractor - wagons	50,665		1.0		3,505		2.9		1,145		1.6	
Tractor pulling equipment or alone	143,458		2.9		9,166		7.6		3,020		4.2	
Combines	13,965		0.3		1,100		0.9		503		0.7	
Subtotal		1,747,101		34.9		80,065		66.0		43,499		60.8
Other:												
School buses	46,800		0.9		9,450		7.8		6,570		9.2	
Post office	55,387	102,187	1.1	2.0	10,373	19,823	8.6	16.4	6,387	12,957	8.9	18.1
Grand total		5,007,338		100.0		121,286		100.0		71,542		100.0

All of this increase in miles driven was from the abandonment of the three miles of non-dead-end road in H_2 solution. Slightly over 60 percent of the increased traffic was for farm purposes, mostly by pick-up trucks. The remaining increased miles were split nearly evenly between household purposes and school buses and postal service vehicles. There was no increase in the miles driven on the 37 miles of dead-end roads which had been converted to private drives; overhead traffic on these roads had been rerouted in the H_1 solution or by the conversion of the three miles of non-dead-end roads in the H_2 solution.

Table 28 shows the estimated travel cost of all base solution traffic and the additional travel cost resulting from removing the 17.75 miles of road in H_1 and converting 40 miles of H_2 road to private drives. The cost of all Hamilton study area travel in the base solution was $1.5 million. About 47 percent of the total cost was for household travel even though 63 percent of total miles was for household travel. Almost 49 percent of the cost was for farm travel; yet only 35 percent of total miles was farm travel. Only 4.5 percent of the total cost was for school bus and post office travel.

In the H_1 solution, total cost increased $58,164, an increase of 3.9 percent over the base solution cost. Over 70 percent of the increased travel cost was for farm travel. The largest increase in farm travel cost was for pickup trucks, followed by tractors pulling equipment and timeliness cost. Household travel costs were only seven per-

Table 28. Estimated cost of all travel in the base solution and change in travel cost in each of two solutions with reduced miles of road, by vehicle groups, Hamilton County study area, 1982.

Type of travel	Base solution				H_1 (17.75 miles)				H_2 (40 miles)			
	Cost		Percent of total		Cost		Percent of total		Cost		Percent of total	
Household:												
Auto	$637,568		42.7		$ 3,181		5.5		$3,273		10.5	
Pickup	35,448		2.4		66		0.1		194		0.6	
Trucks	27,447		1.8		807		1.4		91		0.3	
Subtotal		$700,463		46.9		$ 4,054		7.0		$ 3,558		11.4
Farm:												
Auto	$ 12,336		0.8		$ 1,124		1.9		$ 294		0.9	
Pickup	383,625		25.7		14,064		24.2		9,359		30.0	
Trucks	53,135		3.6		3,318		5.7		324		1.1	
Tractor - wagons	70,982		4.7		4,317		7.4		1,495		4.8	
Tractor pulling equipment or alone	183,558		12.3		10,674		18.4		4,281		13.7	
Combines	21,920		1.5		1,565		2.7		743		2.4	
Timeliness	0		0		5,718		9.8		2,844		9.1	
Subtotal		725,556		48.6		40,780		70.1		19,340		62.0
Other:												
School buses	$ 18,519		1.2		$ 4,025		6.9		$2,608		8.3	
Post office	49,628	68,147	3.3	4.5	9,305	13,330	16.0	22.9	5,709	8,317	18.3	26.6
Grand total		$1,494,166		100.0		$58,164		100.0		$31,215		100.0

cent of the increased costs and school bus and post office travel were almost 23 percent of the increased costs.

In the H_2 solution, travel costs increased $31,215 over the combined base and H_1 solution costs. All of this increased travel cost came from rerouting traffic on the three miles of non-dead-end roads. Most of the additional travel cost on the three miles on non-dead-end roads was for farm traffic, mostly by pickup trucks. School bus and post office travel had 26.6 percent of the additional costs. Household travel had only 11.4 percent of the additional costs.

Table 29 presents the annual cost of maintaining the roads eliminated from the H_1 and H_2 solutions. The net total cost to Hamilton County for maintaining the 17.75 miles of H_1 roads was $64,334. In addition, the net opportunity cost of keeping the land in roads was $19,313, which includes $20,009 in rents forgone minus the $700 per mile of annualized cost of obliterating the road and returning the land to agricultural production. The net result was an annual cost of $83,647 for keeping the 17.75 miles of H_1 roads in the county system.

The total cost to the county or the public for keeping the 40 miles of H_2 roads was $173,521. On a per mile basis, the cost to the county was somewhat lower for the H_1 miles than for the H_2 miles, primarily because the abandonment of the H_1 roads resulted in a relatively large amount of traffic rerouted to other roads.

The private drive road and bridge maintenance and road reconstruction costs for the 40 miles of H_2 roads were estimated to be $82,546. This was an average maintenance and reconstruction cost of $2,064 per

mile of private road. There are nine bridges on the 40 miles of H_2 roads. The average size of these bridges is 880 square feet. At 80 cents maintenance cost per square foot, the average annual bridge maintenance cost was $704 per year. The smallest bridge is 408 square feet, and the largest bridge is 2,000 square feet. Assuming these costs would be paid by abutting land owners, the net cost of keeping the H_2 roads in the county system was $90,975.

Table 29. Estimated total annual cost of keeping the H_1 and H_2 roads in the Hamilton County road system, 1982.

Type of cost	Annual cost H_1	Annual cost H_2
Cost to the county		
Variable maintenance	$-5,712	$ 1,680
Fixed maintenance	42,067	95,985
Resurfacing	11,145	30,226
Reconstruction	14,482	39,296
Bridge maintenance	2,352	6,334
Total cost to the county	$64,334	$173,521
Less		
Private drive road maintenance	---	-57,765
Private drive bridge maintenance	---	- 6,334
Private drive reconstruction	---	-18,447
Road obliteration	696	---
Plus		
Land rental value	20,009	---
Net Cost	$83,647	$ 90,975

Table 30 summarizes the results of the analysis of the H_1 and H_2 solutions. The benefit-cost ratio for removing the 17.75 miles of H_1 gravel roads from the Hamilton County road system was 0.70. This means that the traveling public incurs 70 cents in additional driving costs for each dollar saved by removing the roads from the system. The benefit-cost ratio for the H_2 solution was 0.34. This means that the traveling public would have incurred 34 cents of traveling cost for each dollar saved by converting the 40 miles of gravel roads to private drives. The savings from converting the H_2 roads to private drives is net of the private maintenance and reconstruction costs. If these roads were converted to private drives, the private drive maintenance and reconstruction costs would most likely be borne by the residents and landowners on the private drives.

Table 30. Benefit-cost ratios for the Hamilton County study area by computer solution.

Benefit-cost components	Computer solution	
	H_1	H_2
Benefits to the traveling public for keeping the H_1 and H_2 roads in the system	$58,164	$31,215
Costs of keeping the H_1 and H_2 roads in the system	83,647	90,975
Benefit-cost ratios	0.70	0.34
Change in:		
A. miles of roads	-17.75	-40
B. number of bridges	-5	-9

Table 31 shows the base solution average number of vehicles per day traveling on the H_1 and H_2 roads. Over 72 percent of the roads abandoned in the H_1 solution had 10 or fewer vehicles per day, and 27 percent had between 11 and 20 vehicles per day. This suggests that roads with 20 or fewer vehicles per day serving no access points, located in areas with a core of properly spaced paved roads, yield lower returns to the traveling public than the cost of keeping the roads in the system.

Table 31. Average number of vehicles traveling over the Hamilton study area H_1 and H_2 roads in the base solution.

Average number of vehicles per day	Number of sections of road	
	H_1	H_2
0-10	29	41
11-20	11	26
21-30	1	19
31-40	0	5
Over 40	0	2

About half of the H_2 road segments had 10 or fewer vehicles per day, and almost 28 percent of the H_2 roads had 21 or more vehicles per day. Most of the H_2 roads were dead-end roads. Converting dead-end roads to private drives creates no change in travel miles.

The major conclusions from the Hamilton County study area analysis are:

1. There is a large potential cost saving from reducing the number of miles of low volume roads that serve no property

accesses in areas where the remaining road system is of relatively high quality. Areas within a large number of counties in north central and northwest Iowa fall in this category.

2. The largest cost savings potential is in converting dead-end roads to private drives. This cost savings potential exists in all counties. An alternative to converting these roads to private drives is to keep them in the public road system but reduce the level of maintenance and county liability on these roads.

CHAPTER VI

IMPACT OF ROAD ABANDONMENT AND PRIVATE DRIVES BY TYPE OF TRAVEL

The major impact of road abandonment on travel miles and costs falls on farm travel. In four of the six abandonment and private drive solutions, the change in farm miles driven was greater than the change in miles driven by household, post office and school bus miles. The change in farm travel costs was also greater than the change in household, school bus and post office travel costs in all Hamilton and Shelby County study area solutions. Only the large amount of household traffic in the Linn County study area made the impacts of abandonment greater on households than on farms in the Linn County study area.

There are two major reasons why the impacts of road abandonment are greater on farms than on household traffic:

1. The per mile cost of most farm vehicle travel is higher than the per mile cost of vehicles serving households.
2. The relatively short distances of most farm trips reduces the rerouting options and therefore increases the additional miles required to reach the destinations.

The impacts of road abandonment vary among farms. Obviously, the farmers most impacted by road abandonment are those who use the roads that would be abandoned. However, as shown in Table 32, farmers who operate a large number of tracts of land incur a larger share of total farm equipment travel than farmers who operate a small number of tracts of land.

Table 32. Percent increase in farm equipment miles resulting from road abandonment and percent of farmers operating six or more tracts of land, Hamilton and Shelby County study areas.

Vehicle	Percent increase in total miles driven	
	Hamilton	Shelby
Tractor-wagon	19.6	14.2
Tractor pulling equipment or alone	18.4	13.3
Combines	32.3	25.4
Weighted average	20.0	14.1

In the Hamilton County study area, the 12.6 percent of farmers who operate six or more tracts of land incurred 20 percent of the change in total farm equipment miles resulting from the H_1 road abandonments. In the Shelby County study area, the six percent of the farmers operating six or more tracts of land had 14.1 percent of total change in farm equipment miles resulting from abandonment of the S_1, S_2, and S_3 roads. Moreover, these large farmers tend to use the very large tractors and combines which have the highest cost per mile of travel. Therefore, large farmers will incur an even larger share of the total change in travel costs resulting from a reduction in the total road system.

School buses and post office vehicles incur larger changes in miles driven than the household travel for the following reasons:

1. School buses must serve all residences with school age children and post office vehicles must serve all residences.

This service requirement limits the ability of school districts and the postal service to adjust their routes to minimize distance traveled in response to road abandonment.

2. The vehicle cost per mile of school buses and post office vehicles is higher than for the vehicles serving household travel.

If dead-end roads are converted to private drives, post office regulations require that rural residences continue to receive direct mail service at the present mail box location. There are no regulations that require school buses to continue to pick up and deliver children to residences on private drives. The decision to serve these residences directly rests with individual school districts.

Accident Liability on Private Roads

Once a public road is transferred to private property, the property owner is responsible for accident liability. A major question arising from the transfer of responsibility is "what is the impact of the accident liability for private drives on insurance rates and coverage." To obtain information on this question, three insurance companies that sell large amounts of farm insurance in Iowa were asked to make a judgment on the impacts on insurance rates of converting public roads to private drives.

The responses varied among the three insurance companies. All three company representatives indicated that there was insufficient exposure from converting public roads to private drives to statisti-

cally determine the impact on rates and coverage. The sales representative of insurance company one indicated that the increased exposure on longer private lanes could increase the premiums on the liability coverage by up to 10 percent, or a total additional cost of between $5 to $10 per farm per year.

The underwriter of the second insurance company indicated that most of the large liability claims against farmers are for accidents involving farm equipment on public roads. Thus, converting public roads to private roads would reduce the liability exposure of farm equipment on public roads. Moreover, private roads would reduce the probability of liability claims against farmers resulting from animal escape. The same underwriter felt that converting public roads to private drives could reduce liability premiums, or at the worst, result in no change in premiums.

The underwriter of insurance company three indicated that "turning public roads into private drives would increase the insurance company's exposure and hence rates unless:

a. the road can be made to appear as a private drive to the traveling public by means of a gate, a large sign close to the edge of the road or other devices, and

b. the road is maintained to the degree that a reasonable and prudent person would maintain a private drive."

On the issue of multiple ownership of the private drive, the sales representative of insurance company one stated that two or more owners of the private drive would create litigation problems for the

insurance companies. The underwriter representatives of insurance companies two and three stated that multiple ownership of the private drive would create no problems which would increase liability rates.

Legal and Political Implications

In addition to all the economic costs associated with the abandonment of roads which are included in the determination of benefit-cost ratios in this study, there is one other possible cost which should be considered. There can be substantial legal costs and damage awards associated with a road abandonment. The possibility and extent of such costs depends in large part upon the state laws in effect in the various states. Since these costs vary widely from case to case, it was not possible to include these costs in the benefit-cost ratios in this study.

It is possible that the present laws in some states may preclude any possibility of road abandonment even though all other costs considered, including the shifting of road costs from the public to the private sector, indicate a net benefit from such abandonments. In fact, it may require changes in state laws along with a major change in public policy and acceptance, before any of these changes could and would be implemented and accepted. Some of the areas which need to be addressed are:

1. An adequate method of compensation for change from public to private access.

2. A method of arbitration of disputes between adjoining landowners affected by the change and/or the local government authority.
3. Exemption of the local government authority from legal action upon completion of established guidelines.
4. Legislative consideration to strengthen existing laws regarding road abandonment and changing public roads to private roads.
5. A method of educating the public of the benefits and costs of alternative road system changes to enable the public to improve the quality of its input into the policy-making process.

Suggestions for Further Research

The large cost of developing the computer model, collecting all the data for the three study areas and running the alternative solutions limited the number of investment strategies that could be examined in this study. There is a need to examine the benefits and costs of additional investment strategies, such as paving selected core roads, changing property access locations and simultaneously abandoning other roads or lowering the maintenance standards on other roads.

The current farm crisis is forcing major structural changes on agriculture. These structural changes may result in fewer but larger farmers. There is a need to estimate the impact of these changes on

traffic levels and the implications of the changing traffic levels on the benefit-cost ratios.

This study incorporated a large number of roads and all property access points in the model in an attempt to minimize error from the failure to include all traffic in each solution. The large computer cost of each solution limited this analysis to groups of roads, rather than analysis of individual roads. A smaller computer model that can be run on a microcomputer is needed to analyze the investments and costs of alternative investment strategies on individual road segments. A small microcomputer model is currently under development and will be made available for public use. There will be a need to test the results of this small model to determine how closely they compare with the results of the large model that was used in this study.

APPENDIX A

DESCRIPTION OF THE MODEL

The basic purpose of this appendix is to present the mathematical model and computer algorithm used to estimate the benefits of alternative investment strategies in a local rural road and bridge system. In addition, the benefit-cost models used to evaluate alternative investment strategies are presented.

The network model used in this analysis finds all the minimum cost routes of traveling from each origin to its specified destination for a given vehicle type. A network consists of a set of nodes connected by a set of arcs. A node represents a point where a trip originates, is relayed or terminates. An arc is the road distance between two nodes; arcs allow traffic to flow between nodes.

Define $Q = (q_1, q_2, q_3, q_4)$ to be a vector where each of its components denote the following:

q_1 = the code number for the location of the origin;

q_2 = the code number for the location of the destination;

q_3 = the code number for the vehicle type used;

q_4 = the number of trips made.

Define A to be the set of all Q gathered from the questionnaire. The model can be expressed as a linear programming problem as follows:

$$\text{Minimize} \sum_{Q} q_4 \, G_Q \tag{5}$$

$$Q \in A$$

subject to $\sum_j f_{q_1 j} - \sum_j f_{jq_1} = 1$ for all $Q \varepsilon A$ (6)

$\sum_j f_{q_2 j} - \sum_j f_{jq_2} = -1$ for all $Q \varepsilon A$ (7)

$\sum_j f_{ij} - \sum_j f_{ji} = 0$ for $i \neq q_1$,

$i \neq q_2$ for all $Q \varepsilon A$ (8)

$WT_{ij} \geq WGq_3$ for all $Q \varepsilon A$ (9)

$f_{ij} = 0, 1$ for all $Q \varepsilon A$ (10)

where:

$$G_Q = \sum_i \sum_j f_{ij} \, Dist_{ij} \, (CPMG_{q_3} \, G_{ij} + CPMD_{q_3} \, D_{ij} + CPMP_{q_3} \, H_{ij}) \quad (11)$$

= the cost of making one trip from origin q_1 to destination q_2 with vehicle q_3;

f_{ij} = the amount of traffic flowing from the ith node to the jth node;

$Dist_{ij}$ = the distance from the ith node to the jth node;

$CPMGq_3$ = the cost per mile of traveling over a gravel surface with vehicle q_3;

G_{ij} = 1 if the arc from the ith node to the jth node has a gravel surface otherwise, $G_{ij} = 0$;

CPMDq = the cost per mile of traveling over a dirt surface with vehicle q_3;

D_{ij} = 1 if the arc from the ith node to the jth node has a dirt surface, otherwise, $D_{ij} = 0$;

$CPMP_{q_3}$ = the cost per mile of traveling over a paved surface with vehicle q_3;

H_{ij} = 1 if the arc from the ith node to the jth node has a paved surface, otherwise, $H_{ij} = 0$;

WT_{ij} = the weight constraint of the arc connecting the ith node to the jth node;

WG_{q_3} = the weight of vehicle q_3;

i = beginning node;

j = ending node;

Equation (6) guarantees that the trip specified from origin q_1 to destination q_2 with vehicle type q_3 leaves the origin q_1. Equation (7) guarantees that the trip specified from origin q_1 to destination q_2 with vehicle type q_3 enters destination q_2. Equation (8) ensures the conservation of travel as it moves through the the network. These three equations hold for each Q in set A. Equation (9) ensures the weight constraint of a bridge is not violated.

The problem expressed in equations 5 through 11 can be viewed as finding the minimum cost route from node q_1 (the origin) to node q_2 (the destination) for vehicle type q_3 for each Q in set A. One method of solving this problem is to find the minimum cost route from one node (origin q_1) to all the other nodes in the network. The minimum cost routes can be found efficiently using a computer algorithm.

Dijkstra's Algorithm

Dijkstra's algorithm develops the shortest route tree or route by fanning out from the origin. The advantage of this procedure is that once an arc is part of the tree, it never leaves the tree, and once a node value is permanently assigned, it does not change. Therefore, the shortest route to all permanently labeled nodes are known regardless of whether or not the remaining nodes are labeled. Dijkstra's algorithm has been cited as the most efficient algorithm to solve this problem and is the main solution technique employed in the rural road and bridge model.

Dijkstra's algorithm finds the minimum distance and corresponding route from a specified source node to all other nodes in the network. The algorithm assigns a temporary label and a permanent label to each node in the network. The temporary label represents an estimate of the shortest distance from the source node to each other node. Once a temporary label can no longer be improved, it is declared as permanent. The permanent label represents the minimum distance from the source node to that node.

Initially, every node except the source node is given a temporary label equal to the distance of the arc connecting that node directly to the source node. If a node is not directly connected to the source node, the node is given a temporary label equal to infinity. The permanent label of the source node is set at zero and the permanent labels of the remaining nodes are calculated by the following iterative procedure:

Step I - Inspect all temporary labels of nodes not previously declared permanent. Declare the node with the minimum temporary label as permanent and set its permanent label equal to the value of its temporary label.

Step II - Compare the remaining temporary labels to the sum of the last declared permanent label and the direct distance from the last node declared permanent to the node under consideration. The minimum of these two values is the new temporary label for that node. Then repeat Step I.

This process continues until all the nodes have been declared as permanent. Once a node is assigned a permanent label, its temporary label is excluded from the calculations in Step II.

The algorithm simply works backwards to find the distance minimizing route from the source node to some node j. It compares the permanent label of node j to the sum of the direct distance from some node i to node j and the permanent label of node i. If these two values are equal, then node i is used in finding the shortest distance from the source node to node j and is therefore part of the route. This routine is repeated until the entire route is found.

Example Solution

Suppose the problem is to find the distance minimizing solution in traveling from node 1 (the source node) to all the other nodes in the undirected network given in Figure 1. The numbered nodes are circled and the distances between nodes are shown above the arrows. The distance matrix for this network is shown in Table 33. This matrix

Figure 1. Sample problem network for application of Dijkstra's algorithm.

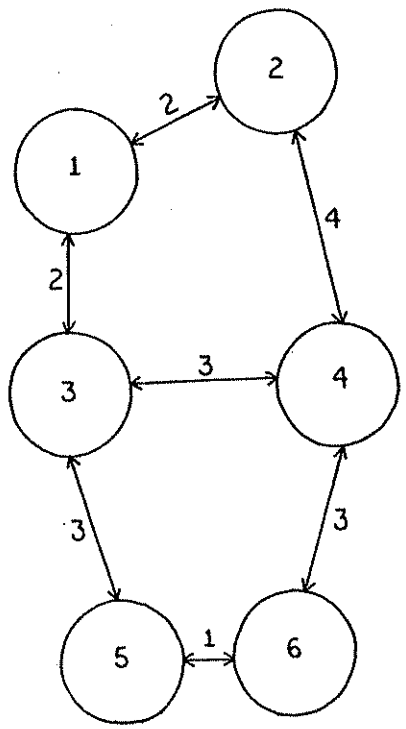


Table 33. Distance matrix from node i to node j for the network given in Figure 1.

node i \ node j	1	2	3	4	5	6
1	∞	2	2	∞	∞	∞
2	2	∞	∞	4	∞	∞
3	2	∞	∞	3	3	∞
4	∞	4	3	∞	∞	3
5	∞	∞	3	∞	∞	1
6	∞	∞	∞	3	1	∞

contains the direct distance of traveling from node i to node j. If a node is not directly connected to another node, the direct distance is set at infinity. The algorithm initially sets the permanent label of node 1 (the source node) to zero and the temporary label of the remaining nodes to infinity. The next step is to compare the temporary label of node j ($j \varepsilon [2,6]$) to the sum of the permanent label of node one and the direct distance from node 1 to node j. The minimum of these two values is the new temporary label of node j. The direct distance from node 1 to node j is found in the jth column of the first row in the distance matrix.

The third step is to find the minimum value of the updated temporary labels and declare that node as permanently labeled. This is shown in Table 34, with the [ ] indicating the node as being declared permanently labeled. In the case of ties, a node is chosen arbitrarily. Step four is similar to the second step except node 2 is now the last permanently labeled node. Hence the sum of the permanent label of node 2 and the direct distance from node 2 to node j ($j \varepsilon [3,6]$) is compared with the temporary label of node j. The remaining steps are summarized in Table 34.

The distance matrix and the permanent labels are used to find the distance minimizing routes. Suppose the problem is to find the shortest route from node 1 to node 6. The first step is to find the node preceding node 6 on the shortest route. Using the sixth column of the distance matrix and the permanent labels, the permanent label of node 6

Table 34. Summary of the computational steps used in solving the same problem via Dijkstra's algorithm.

node / step	1	2	3	4	5	6
1	[0]	∞	∞	∞	∞	∞
2		min(∞,0+2)=2	min(∞,0+2)=2	min(∞,0+∞)=∞	min(∞,0+∞)=∞	min(∞,0+∞)=∞
3		[2]	2	∞	∞	∞
4			min(2,2+∞)=2	min(∞,2+4)=6	min(∞,2+∞)=∞	min(∞,2+∞)=∞
5			[2]	6	∞	∞
6				min(6,2+3)=5	min(∞,2+3)=5	min(∞,2+∞)=∞
7				[5]	5	∞
8					min(5,5+∞)=5	min(∞,5+3)=8
9					[5]	8
10						min(8,5+1)=6
11						[6]

is compared with the sum of the permanent label of node i ($i \varepsilon [1,5]$) and the direct distance from node i to node 6. If these two values are equal, as in the case when i = 5, then that node precedes node 6 on the optimal route. The next step is to find the node which precedes node 5 on the optimal route. Hence the permanent label of node 5 is compared with the sum of the permanent label of node i ($i \varepsilon [1,4]$) and the direct distance from node i to node 5. This process is repeated until the entire route is found. The reader can verify that the optimal route from node 1 to node 6 is 1-3-5-6.

Algorithm Modifications

Dijkstra's algorithm was modified slightly in the application to the rural road and bridge problem. The first alteration was to eliminate the distance matrix. There are over 500 nodes in each of the three study areas. This means the distance matrix would be larger than a 500 x 500 matrix. Even though the distance matrix is symmetric, the computer storage requirement exceeded 900K. The following method reduced the amount of computer storage to 156K and greatly increased the computational efficiency of Dijkstra's algorithm.

Figure 1, which has 6 nodes and 14 arcs, illustrates the alteration. First, two arrays, array A and array B, were dimensioned to the number of arcs in the network. Array A contains the node numbers that are directly connected to each node and array B contains the direct distance. Secondly, two arrays, array P1 and array P2, were dimensioned to the number of nodes in the network. The ith cell in

array P1 contains the beginning location of the node numbers connected to node i stored in array A, while the ith cell in array P2 contains the ending location of node numbers connected to node i stored in array A.

The new computer representation of the network is shown in Table 35. The fourth cell (i.e. when i = 4) of P1 and P2 contain the numbers 8 and 10 respectively. This indicates that the nodes directly connected to node 4 are stored in cells 8, 9 and 10 of array A and the distances are stored in cells 8, 9 and 10 of array B. Storage area requirements are reduced because only the nodes directly connected to other nodes and the respective distances are stored.

Table 35. An alternative method of representation of the network presented in Figure 1.

i	P1	i	P2		A		B
1	1	1	2	1	2	1	2
2	3	2	4	2	3	2	2
3	5	3	7	3	1	3	2
4	8	4	10	4	4	4	4
5	11	5	12	5	1	5	2
6	13	6	14	6	4	6	3
				7	5	7	3
				8	2	8	4
				9	3	9	3
				10	6	10	3
				11	3	11	3
				12	6	12	1
				13	4	13	3
				14	5	14	1

The computational efficiency of Dijkstra's algorithm is also increased with this new computer representation of the network. This alteration limits the second step of Dijkstra's algorithm and the route finding process to only the nodes directly connected to the last permanently declared node.

Thus far, Dijkstra's algorithm has been discussed only in terms of minimizing the distance between two nodes. The algorithm can also be used to minimize the cost of traveling between two nodes. This is accomplished by storing the direct cost of traveling from node i to node j in array B rather than the direct distance from node i to node j. The direct cost of traveling from node i to node j is the product of the direct distance from node i to node j and the vehicle cost per mile of the specific vehicle type. The vehicle cost depends on the road surface of the arc connecting node i to node j, as well as on the vehicle type. A separate computer run of the algorithm would be necessary to estimate travel cost for each vehicle type, since the cost of traveling over a paved, gravel, or dirt surface is different for all vehicles. Since there were over 100 different vehicles in this analysis, a method to decrease the number of computer runs was imperative. With a few simplifications, groups of vehicles could be routed in the same computer run. The ratios of the vehicle-mile cost on gravel surface to vehicle-mile cost on paved surface and the ratios of dirt surface vehicle cost relative to paved surface cost were calculated for each type of vehicle. The vehicle costs per mile and their surface adjustment ratios are presented in Table 36. The values of these ra-

Table 36. Adjusted vehicle variable costs in cents per mile and surface adjustment ratios by vehicle type.

Type of vehicle	Cents per mile			Surface adjustment ratios	
	Paved	Gravel	Earth	Paved to gravel	Paved to earth
Automobile	20.2	28.1	35.7	1.39	1.77
Pickup	24.4	33.9	43.1	1.39	1.77
Pickup pulling trailer	35.3	49.0	62.4	1.39	1.77
Commercial van	40.2	55.9	71.1	1.39	1.77
Commerical semitrailer					
Empty	51.5	77.8	99.0	1.47	1.92
Loaded	55.4	82.0	108.5	1.48	1.96
Garbage truck	77.2	113.4	148.3	1.47	1.92
Farmer-owned single axle truck					
50 percent loaded	32.3	47.2	61.7	1.46	1.91
Pulling empty pup	33.5	48.9	65.0	1.46	1.91
Pulling loaded pup	39.6	57.8	75.7	1.46	1.91
Pulling empty grain wagon	32.9	48.0	62.8	1.46	1.91
Pulling loaded grain wagon	39.0	56.9	74.5	1.46	1.91
Farmer-owned tandem axle truck					
Empty	37.1	54.6	71.3	1.47	1.92
Loaded	42.4	62.7	83.0	1.48	1.96
Pulling empty pup	40.9	59.7	78.1	1.46	1.91
Pulling loaded pup	53.0	77.4	101.2	1.46	1.91
Pulling empty grain wagon	40.3	58.8	76.9	1.46	1.91
Pulling loaded grain wagon	52.4	76.5	100.1	1.46	1.91
Farmer-owned semitrailer					
Empty	33.5	48.9	64.0	1.46	1.91
Loaded	37.4	54.6	71.4	1.46	1.91
Tractor (alone)	118.4	135.0	135.0	1.14	1.14
Tractor pulling:					
Equipment	119.4	136.2	136.2	1.14	1.14
125-bushel wagon - empty	118.7	135.3	135.3	1.14	1.14
125-bushel wagon - loaded	120.5	144.6	144.6	1.20	1.20
250-bushel wagon - empty	118.7	135.3	135.3	1.14	1.14
250-bushel wagon - loaded	122.3	139.5	139.5	1.20	1.20
350-bushel wagon - empty	118.8	135.4	135.4	1.14	1.14
350-bushel wagon - loaded	123.9	148.7	148.7	1.20	1.20
450-bushel wagon - empty	136.9	156.0	156.0	1.14	1.14
450-bushel wagon - loaded	145.6	174.7	174.7	1.20	1.20
550-bushel wagon - empty	137.7	156.9	156.9	1.14	1.14
550-bushel wagon - loaded	148.3	177.9	177.9	1.20	1.20
350-bushel tandem - empty	137.1	156.3	156.3	1.14	1.14
350-bushel tandem - loaded	150.7	180.8	180.8	1.20	1.20
450-bushel tandem - empty	145.9	166.3	166.3	1.14	1.14
450-bushel tandem - loaded	166.0	199.2	199.2	1.20	1.20
650-bushel grain buggy - empty	140.3	160.0	160.0	1.14	1.14
650-bushel grain buggy - loaded	151.9	182.3	182.3	1.20	1.20
Combines:					
2-row combine	101.7	113.9	113.9	1.12	1.12
4-row combine	146.1	163.6	163.6	1.12	1.12
6-8 row combine	161.7	181.1	181.1	1.12	1.12

tios were found to be very similar for vehicles with similar weight characteristics. Thus, for simplicity and computer efficiency, vehicles with similar ratio values were grouped together. For example, the ratios for cars, pickups, commercial delivery vans and pickups pulling a trailer, indicated that the cost per mile mile of traveling over a gravel surface is 1.39 times the cost of traveling over a paved surface, and the cost per mile of traveling over a dirt surface is 1.77 times the cost of traveling over a paved surface. Within each group of vehicles, pseudo distances are calculated based on the ratios. All these grouped vehicles then comprise a single computer run. For the above example, the pseudo distance of a gravel arc is equal to 1.39 times the actual distance of the arc, and 1.77 times the actual distance of the arc, for a dirt surface. If the arc has a paved surface, the pseudo distance is equal to the actual distance of the arc. Equations (12) and (13) express the relative cost of traveling over a gravel and dirt surface for all these vehicle types.

$$\frac{CPMG_{q_3}}{CPMP_{q_3}} = 1.39 \tag{12}$$

$$\frac{CPMD_{q_3}}{CPMP_{q_3}} = 1.77 \tag{13}$$

where the variables are as previously defined. Use of these ratios results in slightly different vehicle costs per mile in Table 36 than are presented in Tables 12, 13 and 14. These slight differences caused

by the ratios greatly reduced the computational costs of the analysis and made only a slight difference in the results of the analysis. The variable costs per mile for farm tractors operating alone, pulling farm equipment and various sizes of wagons are averaged—over all sizes of tractors weighted by the frequency of tractor sizes obtained from the questionnaire.

Substituting equations (12) and (13) into equation (11) and rewriting yields equation (14).

$$G_{Q_3} = CPMP_{q_3} \sum_i \sum_j f_{ij} \left(Dist_{ij} H_{ij} + 1.39\ Dist_{ij} G_{ij} + 1.77\ Dist_{ij} D_{ij}\right) \tag{14}$$

Equation (14) is minimized when the sum of the terms in brackets is minimized for each origin and destination pair. The psuedo distance of an arc is the sum of the terms in parentheses. Thus, Dijkstra's algorithm can be used in a single computer run to minimize the total transportation cost of several vehicles by minimizing the psuedo distances of the arcs. The minimized cost of q_4 trips from an origin to a destination with vehicle type q_3 is simply the minimized psuedo distance of traveling through the network multiplied by the vehicle type's cost per mile of traveling over a paved surface and by q_4 trips.

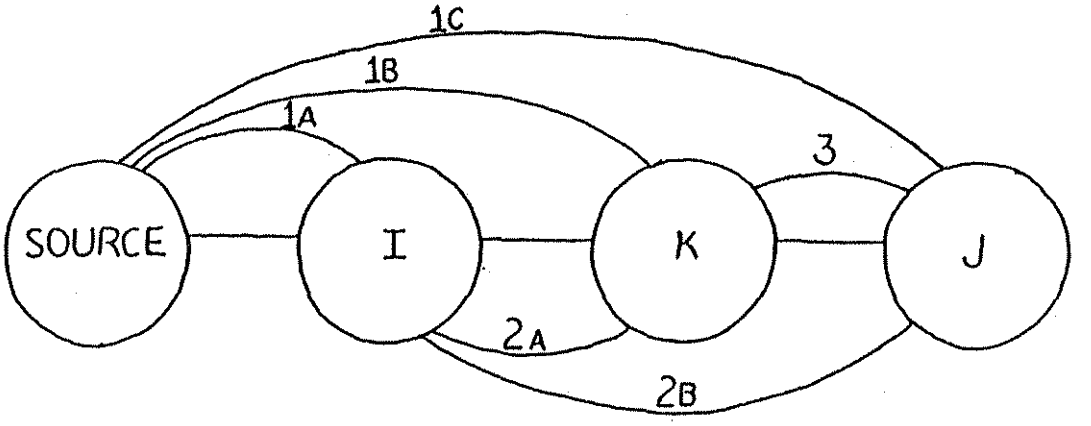
The computer program picks a node in the network as the source node and begins Dijkstra's iterative procedure on the psuedo distance of the arcs. The final result will be the minimized cost of traveling from the source node to all the other nodes in the network. But upon

closer inspection, other minimal routes are being obtained. Dijkstra's algorithm operates on the logic that if a shortest path from the source node to node j is known and node i belongs to this path, then the minimal path from the source node to node i is known, and it is the portion of the original path ending at the at the ith node. This logic can be extended to two nodes i and k on the known shortest path from the source node to node j. If this is the case, as shown in Figure 2, the following minimum cost routes are known:

1) The minimum cost routes from the source node to the ith, k^{th} and j^{th} nodes are known. The minimum cost of the routes is the cost per mile of traveling over a paved surface with vehicle q_3 multiplied by the value of the permanent label for the ith, k^{th} and j^{th} nodes, respectively.
2) The minimum cost routes from the ith node to the kth and j^{th} node are known. The minimal distance of the route from the ith node to the jth node is the cost per mile of traveling over a paved surface with vehicle q_3 multiplied by the difference of the values of the permanent labels for nodes k and i. The minimum cost from node i to node j is found in a similar manner.
3) The minimum cost route from the kth node to the jth node is known. The minimum cost of this route is simply the cost per mile of traveling over a paved surface with vehicle q_3 multiplied by the difference of the permanent labels for nodes j and k.

The computer model selects a node as the source node and calculates the psuedo distance from the source node to all the other nodes in the network. The computer checks to see if the minimized cost route between any of the origin-destination pairs lie on the minimized cost

Figure 2. Minimum routes found when the minimal route from the source node to node j is known and nodes i and k lie on the minimal route.



path from the source node to any other node in the network. If the origin-destination pair is on any of these routes, all the minimized cost routes between the origin and destination will have been calculated. The number of trips between the origin and destination will then be spread evenly over all the routes which are of equal cost. If the route for an origin-destination pair is not found, the computer will select another node to be the source node. This process continues until a minimized cost route is found for all origin-destination pairs.

Benefit-Cost Analysis

Where public investment projects are designed to provide for private sector production, an appropriate benefit-cost ratio is:

$$\frac{\text{Annualized value of net benefits to the private sector}}{\text{Annualized value of public costs}}$$

Using this form, projects with ratios greater than one can be ranked and selected in order of their rank until public funds are exhausted.

The following form was used to evaluate the question "should a road segment, group of road segments, or bridge remain in the county road system?"

$$\frac{B}{C_{r_A}} = (TC_r - TC_{r-1}) \left[(MC_{r-1} - MC_r) + \frac{i\,(1+i)^{n_1}}{(1+i)^{n_1} - 1} REC_r + \frac{i\,(1+i)^{n_2}}{(1+i)^{n_2} - 1} RES_r + VL_r - (i)ROW_r \right]^{-1} \quad (15)$$

where:

$\frac{B}{C_{r_A}}$ = the abandonment benefit cost ratio of the rth arc

MC_{r-1} = the total maintenance cost before the rth arc is abandoned

MC_r = the total maintenance cost after the rth arc is abandoned

REC_r = the roadbed reconstruction costs of the rth arc

RES_r = the resurfacing costs of the rth arc

ROW_r = the cost of converting the right-of-way of the rth arc to agricultural production;

TC_{r-1} = total vehicle transportation costs after the rth arc is not maintainted;

TC = total vehicle transportation costs if the rth arc is maintained;

VL_r = value of the land if the rth arc is not maintained;

i = interest rate;

n_1 = number of years between reconstructions of the rth arc;

n_2 = the number of years resurfacings of the rth arc.

If the value of the ratio in equation (15) is less than one, the net benefit to traveling public of keeping the road in the system is less than the cost to the county of keeping the arc in the system. If the ratio is greater than one, the benefit to the traveling public of keeping the road is greater than the cost to the county of keeping the road.

The following was used to evaluate the question "should road segment or group of road segments be converted to private drives?"

$$\frac{B}{C_{jpd}} = (TC_j - TC_{j-1}) \left[(MC_{j-1} - MC_j) + \frac{i(1+i)^{n_1}}{(1+i)^{n_1} - 1} REC_j + \frac{i(1+i)^{n_2}}{(1+i)^{n_2} - 1} REC_j - \frac{i(1+i)^{n_3}}{(1+i)^{n_3} - 1} REC_{pd} \right]^{-1} \quad (16)$$

where:

$\frac{B}{C}_{jpd}$ = private drive benefit-cost ratio of the jth arc.

TC_j = total vehicle transportation costs after the jth arc is converted to a private drive.

TC_{j-1} = total vehicle transportation costs if the jth arc is not converted to a private drive.

MC_{j-1} = total maintenance cost if the jth arc is not converted to a private drive.

MC_j = total maintenance cost after the jth arc is converted to a private drive.

REC_j = roadbed reconstruction costs of the jth arc.

RES_j = resufacing cost of the jth arc.

REC_{pd} = reconstruction cost for a private drive.

MC_{pd} = maintenance cost for a private drive.

n_1 = the number of years between reconstruction of the rth arc.

n_2 = the number of years between resurfacing of the rth arc.

n_3 = the number of years between private drive reconstructions

If legal costs or damage awards were included in the analysis, these costs would be subtracted from the denominator in equations (15) and (16).

APPENDIX B

MAINTENANCE, RECONSTRUCTION, AND RESURFACING COSTS

Paved Maintenance Cost

The basic assumption underlying the maintenance cost for a paved road is that a portion of the cost varies directly with the number of axle loadings passing on the road. Therefore, the first step in estimating the maintenance costs was to express all vehicles in terms of equivalent 18,000-pound (18-kip) axle loadings that the road would sustain through one pass by each vehicle. The remaining portion of the maintenance cost is fixed and is independent of the traffic level or composition. This fixed portion of the maintenance costs is associated with signing, slope erosion, ditching and snow removal.

Variable Maintenance Cost

Pavements are designed to withstand the projected number of 18-kip loadings during the expected life of the road, usually 20 years. An increase in the projected number of 18-kip loadings (additional and/or heavier vehicles) within a given period of time will increase the maintenance cost of the road surface.

The measure of pavement condition used is the Pavement Serviceability Index (PSI). This surface roughness index ranges from 5.0 downward to 0.0 with the upper limit being the indication of the best condition possible.

Tables 37 and 38 show the remaining 18-kip load applications a pavement can be expected to sustain before resurfacing is needed at PSI

Table 37. Remaining 18-kip applications to a rigid pavement in very good condition before resurfacing will be required at PSI = 2.0, in thousands of applications by alternative design terms.*

Design term	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
6.	--	--	--	--	--	--	--	--	--	--
7.	1,309	1,445	1,592	1,753	1,927	2,116	2,322	2,544	2,785	3,046
8.	3,327	3,632	3,961	4,316	4,700	5,112	5,558	6,035	6,549	7,102
9.	7,695	8,331	9,016	9,743	10,529	11,363	12,260	13,219	14,236	15,332
10.	16,489	17,730	19,046	20,450	21,943	23,523	25,212	26,996	28,900	30,917
11.	33,045	35,310	37,714	40,244	42,914	45,751	48,753	51,928	55,259	58,790
12.	62,503	66,435	70,550	74,920	79,488	84,333	89,392	94,733	100,369	106,243
13.	112,460	118,932	125,777	132,954	140,475	148,320	156,603	165,272	174,341	183,823

* Initial road PSI = 4.5

Source: American Association of State Highway Officials Committee on Transportation, August 1962. Manual of Instructions for Pavement Evaluation Survey.

Table 38. Remaining 18-kip applications for a flexible pavement in very good condition before resurfacing will be required at PSI = 2.0 for alternative design terms.* **

Design term	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
2.	(416)	(656)	(1,021)	(1,530)	(2,271)	(3,315)	(4,763)	(6,746)	(9,428)	(13,309)
3.	18	24	32	42	55	71	92	117	148	189
4.	233	289	357	438	535	651	788	950	1,141	1,366
5.	1,629	1,937	2,294	2,712	3,196	3,758	4,406	5,154	6,014	7,003
6.	8,137	9,434	10,914	12,601	14,522	16,705	19,177	21,979	25,147	28,717
7.	32,745	37,264	42,346	48,037	54,424	61,555	69,515	78,406	88,280	99,293
8.	111,486	125,017	140,043	156,675	175,009	195,285	217,631	242,220	269,296	299,082

*Figures in parentheses are units; all others in thousands.
**Initial PSI = 4.2

Source: American Association of State Highway Officials Committee on Transport--August 1962. Manual of Instructions for Pavements Evaluation Survey.

of 2.0. Therefore, if the pavement was assumed to be new at 4.5 PSI and needing resurfacing at 2.0, the values in Tables 37 and 38 can be used as estimates of the total number of 18-kip loads the pavement can sustain before it needs resurfacing.

The columns in Tables 37 and 38 headed "Design term" are the pavement structure indicators used to determine the number of loads a road can withstand before it requires resurfacing. The origin of the roughness measurement is the AASHTO Road Test of 1958-60. Roughness measured in Present Serviceability Index (PSI) changes from a maximum of 5.0 to a selected value of 2.0 over time indicates an increase in roughness.

The design term relates the number of passes of a standard 18,000 lb. axle load to the load carrying capacity of the various pavement layers. In this study, the design term indicates the number of standard axle loads that can pass over a pavement before the roughness (PSI) reaches 2.0 for each flexible or rigid pavement thickness. The design term for each paved road in the three study areas was computed from pavement type and thickness information supplied by the counties and Iowa Department of Transportation records.

Tables 39 and 40 present the traffic equivalence factors for single axle and tandem axles on rigid pavements. These tables indicate the 18-kip equivalence for a range of kip-loads on rigid pavements with slab thickness ranging from 6 to 11 inches.

Table 39. Traffic equivalence factors for single axles on rigid pavement where PSI = 2.0

Axle load kips	Slab thickness in inches					
	6	7	8	9	10	11
2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
4	0.002	0.002	0.002	0.002	0.002	0.002
6	0.01	0.01	0.01	0.01	0.01	0.01
8	0.03	0.03	0.03	0.03	0.03	0.03
10	0.09	0.08	0.08	0.08	0.08	0.08
12	0.19	0.18	0.18	0.18	0.17	0.17
14	0.35	0.35	0.34	0.34	0.34	0.34
16	0.61	0.61	0.60	0.60	0.60	0.60
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.55	1.56	1.57	1.58	1.58	1.59
22	2.32	2.32	2.35	2.38	2.40	2.41
24	3.37	3.34	3.40	3.47	3.51	3.53
26	4.76	4.69	4.77	4.88	4.97	5.02
28	6.59	6.44	6.52	6.70	6.85	6.94
30	8.92	8.68	8.74	8.98	9.23	9.39
32	11.87	11.49	11.51	11.82	12.17	12.44
34	15.55	15.00	14.95	15.30	15.78	16.18
36	20.07	19.30	19.16	19.53	20.14	20.71
38	25.56	34.54	24.26	24.63	25.36	26.14
40	32.18	30.85	30.41	30.75	31.58	32.57

Source: AASHO Interim Guide for Design of Pavement Structures, 1972.

Table 40. Traffic equivalence factors for tandem axles on rigid pavements where PSI = 2.0.

Axle load kips	Slab thickness in inches					
	6	7	8	9	10	11
10	0.01	0.01	0.01	0.01	0.01	0.01
12	0.03	0.03	0.03	0.03	0.03	0.03
14	0.05	0.05	0.05	0.05	0.05	0.05
16	0.09	0.08	0.08	0.08	0.08	0.08
18	0.14	0.14	0.13	0.13	0.13	0.13
20	0.22	0.21	0.21	0.20	0.20	0.20
22	0.32	0.31	0.31	0.30	0.30	0.30
24	0.45	0.45	0.44	0.44	0.44	0.44
26	0.63	0.64	0.62	0.62	0.62	0.62
28	0.85	0.85	0.85	0.85	0.85	0.85
30	1.13	1.13	1.14	1.14	1.14	1.14
32	1.48	1.45	1.49	1.50	1.51	1.51
34	1.91	1.90	1.93	1.95	1.96	1.97
36	2.42	2.41	2.45	2.49	2.51	2.52
38	3.04	3.02	3.07	3.13	3.17	3.19
40	3.79	3.74	3.80	3.89	3.95	3.98
42	4.67	4.59	4.66	4.78	4.87	4.93
44	5.72	5.59	5.67	5.82	5.95	6.03
46	6.94	6.76	6.83	7.02	7.20	7.31
48	8.36	8.12	8.17	8.40	8.63	8.79

Source: AASHO Interim Guide for Design of Pavement Structures, 1972.

Note: For tandem axle loads under 10 kips, the following equivalence factors were utilized: 0.0004 for 4 kips, 0.0014 for 6 kips, and 0.004 for 8 kips.

Tables 41 and 42 present the traffic equivalence factors for single axles and tandem axles on flexible pavements for selected kip loadings and structural numbers.

Table 43 indicates the number and type of axles and the loading on each axle for all vehicles in this study. This table, along with Tables 39, 40, 41 and 42 yield the number of 18-kip equivalent loads that each vehicle applies to a pavement. The 18-kip equivalent number is multiplied by the vehicle yearly traffic level on the road to obtain the total number of 18-kip loadings the vehicle applies to the road. Summing over all vehicle types yields the annual number of 18-kip loadings applied to a road.

For example, suppose a commercial van traveled 10,000 times over a road with a rigid pavement with a slab thickness of six. Table 43 shows the commercial van having two single axles weighing 2,800 and 2,400 pounds, respectively. By interpolating between two and four axle load kips in Table 39, the front axle applies 0.00092 kip equivalents to the road surface, while the rear axle applies 0.00056 kip equivalents. Hence, the commercial van applies 0.00148 kip equivalents to the road on each pass and 14.8 kip equivalents when the commercial van travels over the road 10,000 times.

The total number of 18-kip loadings a road can withstand in its lifetime from Tables 41 and 42 were divided by the life of the road to yield the total number of 18-kip loadings a road can withstand in a year.

Table 41. Traffic equivalence factors for single axles on flexible pavement where PSI = 2.0.

Axle load kips	Structural number 1	2	3	4	5	6
2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
4	0.002	0.003	0.002	0.002	0.002	0.002
6	0.01	0.01	0.01	0.01	0.01	0.01
8	0.03	0.04	0.04	0.03	0.03	0.03
10	0.08	0.08	0.09	0.08	0.08	0.08
12	0.16	0.18	0.19	0.18	0.17	0.17
14	0.32	0.34	0.35	0.35	0.34	0.33
16	0.59	0.60	0.61	0.61	0.60	0.60
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.61	1.59	1.56	1.55	1.57	1.60
22	2.49	2.44	2.35	2.31	2.35	2.41
24	3.71	3.62	3.43	3.33	3.40	3.51
26	5.36	5.21	4.88	4.68	4.77	4.96
28	7.54	7.31	6.78	6.42	6.52	6.83
30	10.38	10.03	9.24	8.65	8.73	9.17
32	14.00	13.51	12.37	11.46	11.48	12.17
34	18.55	17.87	16.30	14.97	14.87	15.63
36	24.20	23.30	21.16	19.28	19.02	19.93
38	31.14	29.95	27.12	24.55	24.03	25.10
40	39.57	38.02	34.34	30.92	30.04	31.25

Source: AASHO Interim Guide for Design of Pavement Structures, 1972.

Table 42. Traffic equivalence factors for tandem axles on flexible pavement where PSI = 2.0

Axle load kips*	Structural number					
	1	2	3	4	6	8
10	0.01	0.01	0.01	0.01	0.01	0.01
12	0.01	0.02	0.02	0.01	0.01	0.01
14	0.02	0.03	0.03	0.03	0.02	0.02
16	0.04	0.05	0.05	0.05	0.04	0.04
18	0.07	0.08	0.08	0.08	0.07	0.07
20	0.10	0.12	0.12	0.12	0.11	0.10
22	0.16	0.17	0.18	0.17	0.16	0.16
24	0.23	0.24	0.26	0.25	0.24	0.23
26	0.32	0.34	0.36	0.35	0.34	0.33
28	0.45	0.46	0.49	0.48	0.47	0.46
30	0.61	0.62	0.65	0.64	0.63	0.62
32	0.81	0.82	0.84	0.84	0.83	0.82
34	1.06	1.07	1.08	1.08	1.08	1.07
36	1.38	1.38	1.38	1.38	1.38	1.38
38	1.76	1.75	1.73	1.72	1.73	1.74
40	2.22	2.19	2.15	2.13	2.16	2.18
42	2.77	2.73	2.64	2.62	2.66	2.70
44	3.42	3.36	3.23	3.18	3.24	3.31
46	4.20	4.11	3.92	3.83	3.91	4.02
48	5.10	4.98	4.72	4.58	4.68	4.83

*For tandem axle loads under 10 kips, the following equivalence factors were utilized: 0.0004 for 4 kips, 0.0014 for 6 kips, and 0.004 for 8 kips.

Source: AASHO Interim Guide for Design of Pavement Structures, 1972.

Table 43. Vehicle axle weights by type of vehicle in pounds.

Vehicle Description	Number of axles	Individual axle loadings*					
		First	Second	Third	Fourth	Fifth	Sixth
Car	2	1,750	1,750	—	—	—	—
Commercial van	2	2,800	2,400	—	—	—	—
Pickup	2	1,750	1,750	—	—	—	—
Single axle truck-half loaded	2	6,150	13,300	—	—	—	—
Tandem axle truck-empty	2	6,900	11,700T	—	—	—	—
Tractor with equipment	3	3,800	12,800	4,000	—	—	—
Pickup with trailer	3	1,750	1,750	6,000T	—	—	—
Garbage truck	2	7,000	29,000T	—	—	—	—
Commercial semitrailer-empty	3	9,000	13,400T	9,500T	—	—	—
Tractor	2	3,800	12,800	—	—	—	—
Tractor with equipment	3	3,800	12,800	4,000	—	—	—
Combine, 2-row	2	8,000	3,000	—	—	—	—
Combine, 4-row	2	12,615	3,700	—	—	—	—
Combine, 6-row	2	13,926	4,640	—	—	—	—
Tractor with 125-bu. wagon-empty	4	3,800	12,800	500	500	—	—
Tractor with 250-bu. wagon-empty	4	3,800	12,800	520	520	—	—
Tractor with 350-bu. wagon-empty	4	3,800	12,800	730	730	—	—
Tractor with 450-bu. wagon-empty	4	3,800	12,800	1,070	1,070	—	—
Tractor with 550-bu. wagon-empty	4	3,800	12,800	2,190	2,190	—	—
Tractor with 2 350-bu. wagons-empty	6	3,800	12,800	730	730	730	730
Tractor with 2 450-bu. wagons-empty	6	3,800	12,800	1,070	1,070	1,070	1,070
Single axle truck with pup-empty	3	5,500	6,600	6,640T	—	—	—
Farm semitrailer-empty	3	9,000	13,400T	9,500T	—	—	—
Tandem axle truck with pup-empty	3	6,900	11,700T	6,640T	—	—	—
Single axle truck with 250-bu. wagon-empty	4	5,500	6,600	520	520	—	—
Single axle truck with 350-bu. wagon-empty	4	5,500	6,600	730	730	—	—
Tandem axle truck with 450-bu. wagon-empty	4	6,900	11,700T	1,070	1,070	—	—
Tractor with grain buggy-empty	3	3,800	12,800	7,240	—	—	—
Tandem axle truck with 550-bu. wagon-empty	4	6,900	11,700T	2,190	2,190	—	—
Tandem axle truck with 2 350-bu. wagon-empty	6	6,900	11,700T	730	730	730	730
Tandem axle truck with 2 450-bu. wagon-empty	6	6,900	11,700T	1,070	1,070	1,070	1,070
Commercial semitrailer-loaded	3	9,800	28,800T	29,400T	—	—	—
Tandem axle truck-loaded	2	20,000	34,000T	—	—	—	—
Farm semitrailer-loaded	3	9,800	33,000T	33,000T	—	—	—
Single axle truck with pup-loaded	3	6,800	20,000	24,000T	—	—	—
Tandem axle truck with pup-loaded	3	20,000	34,000T	24,000T	—	—	—
Tractor with 125-bu. wagon-loaded	4	3,800	12,800	4,000	4,000	—	—
Tractor with 250-bu. wagon-loaded	4	3,800	12,800	7,520	7,520	—	—
Tractor with auger wagon-loaded	3	3,800	12,800	20,000	—	—	—
Tractor with 350-bu. wagon-loaded	4	3,800	12,800	10,530	10,530	—	—
Tractor with 450-bu. wagon-loaded	4	3,800	12,800	13,670	13,670	—	—
Tractor with 550-bu. wagon-loaded	4	3,800	12,800	17,590	17,590	—	—
Tractor with 2 350-bu. wagons-loaded	6	3,800	12,800	10,530	10,530	10,530	10,530
Tractor with 2 450-bu. wagons-loaded	6	3,800	12,800	13,670	13,670	13,670	13,670
Single axle truck with 250-bu. wagon-loaded	4	6,800	20,000	7,520	7,520	—	—
Single axle truck with 350-bu. wagon-loaded	4	6,800	20,000	10,530	10,530	—	—
Tandem axle truck with 450-bu. wagon-loaded	4	18,660	34,000T	13,670	13,670	—	—
Tandem axle truck with 550-bu. wagon-loaded	4	14,820	30,000T	17,590	17,590	—	—
Tandem axle truck with 2 350-bu. wagons-loaded	6	10,000	27,880T	10,530	10,530	10,530	10,530
Tandem axle truck with 2 450-bu. wagons-loaded	6	10,000	15,000T	13,670	13,670	13,670	13,670

*T represents a tandem axle, otherwise the axle is a single axle.

Source: Iowa Department of Transportation, "1982 Truck Weight Study," Ames, Iowa.

Implement and Tractor, 1983, Red Book Issue, Vol. 98, No. 5, 1983.

Unpublished sales brochures, selected farm implement manufacturers, 1983.

Heart of Iowa Coop, Unpublished scale weights, Roland, Iowa, 1983.

Parker Industries, "Gravity Beds and Combine Related Specification Sheets," Jefferson, Iowa.

The average maintenance for county paved roads in each study area was obtained from the Quadrennial Need Study for Study Years 1982 through 2001. The average annual fixed maintenance cost for each study area was subtracted from the study area annual average total maintenance cost to obtain the annual average variable maintenance per mile of paved road. The resulting annual variable maintenance cost per mile of paved road in the three study areas were:

Study area	Annual variable maintenance cost per mile of paved road
Hamilton	$175.60
Shelby	542.40
Linn	427.00

Variable maintenance costs for each paved road were estimated by equation (17).

$$VMC = \frac{KA}{YK} * AVMC * Dist \tag{17}$$

where:

VMC = variable maintenance cost;

KA = the total number of 18-kips applied in 1982;

YK = the yearly allocation of 18-kip applications;

AVMC = the average variable maintenance cost per mile of road;

Dist = the distance of road.

The variable maintenance costs calculated by equation (17) were unrealistically high for many paved country roads in each study area. The lifetime kip loadings of these roads were being consumed in the model in

less than one year. It was assumed, based on past county practices, that county engineers would upgrade the roads rather than rebuild the roads on an annual basis. The upgrading procedure consisted of adding sufficient pavement to increase the lifetime kip loadings to 500,000. Assuming a 20-year life, the additional six inches of pavement would withstand 25,000 18-kip applications per year. The estimated cost of resurfacing a paved road with six inches of pavement for the three study areas are presented in Table 44.

Table 44. Estimated cost of resurfacing by study area.

Study area	Cost per lane mile	Annualized cost per lane mile
Hamilton	$25,881	$2,278.91
Shelby	25,881	2,278.91
Linn	30,684	2,685.96

Equation 18 represents the alternative method of calculating variable maintenance costs for paved roads in this study.

$$VMC = UPC + \left(\frac{KA}{R} * AVMC * Dist\right) \tag{18}$$

where:

UPC = the annualized upgrading cost;

R = 50,000 kip applications spread over 20 years.

The variable maintenance of a paved road used in this analysis is the minimum value of equations (17) and (18). Hence, equation (19) represents the maintenance cost equation for paved roads.

$$MC = (FMC * Dist) + S \quad (19)$$

where:

MC = maintenance cost;

FMC = the fixed maintenance cost per mile of road;

S = the minimum value of variable maintenance cost calculated in equations (17) and (18).

Gravel and Dirt Maintenance Cost

Table 45 expresses maintenance cost for paved, gravel, and dirt roads as a function of average daily traffic (ADT) level and an intercept term. The average daily traffic level was calculated for all gravel and dirt roads in each of the three study areas. The average

Table 45. Maintenance cost per mile of gravel road as a function of average daily traffic and an intercept.

County	Road surface	Cost per average daily traffic	Intercept
Hamilton	paved	$0.94	$1,160
	gravel	4.70	2,376
	dirt	1.52	2,026
Shelby	paved	1.54	1,083
	gravel	8.75	2,765
	dirt	1.52	2,026
Linn	paved	1.94	1,400
	gravel	6.25	2,525
	dirt	1.52	2,026

daily traffic was multiplied by its appropriate coefficient to yield the variable portion of maintenance cost. The total maintenance cost was obtained by adding the fixed portion of maintenance to the variable maintenance cost and multiplying by the distance of the road.

Reconstruction and Resurfacing Costs

Tables 46 and 47 show the reconstruction and resurfacing costs of roads in each of the three study areas obtained from the Quadrennial Need Study for Study Years 1982 through 2001. From Table 45, a lane mile of gravel road in Hamilton County with an ADT of 97 or 99 requires $6,621 in resurfacing costs every 20 years. A gravel road with an ADT of 101 requires $17,454 in resurfacing costs every 60 years. The increase in resurfacing costs by adding 2 ADT is zero when traffic increases from 97 to 99 ADT, while adding 2 more ADT increases resurfacing costs $10,833 when traffic increases from 99 to 101 ADT.

The values in Tables 46 and 47 were interpreted as the reconstruction or resurfacing costs for the midpoint of its ADT group for highway group numbers 3 and 7. Highways are grouped by ease of entry and length of trip. For example, highway group 1 consists of interstate highways with long length trips and full access control. Highway group 8 consists of rural roads with very short trips and no access control. A lane mile of gravel road in Hamilton County with an ADT of 62.50 requires $6,621 in resurfacing costs every 20 years. The midpoint traffic levels for highway group numbers 3 and 6 were 3,250 and 250 ADT respectively. The minimum reconstruction and resurfacing

Table 46. Resurfacing cost per lane mile of road by road type, traffic level and highway group, 1982.

Highway group number	ADT group	Surface type	Study area		
			Hamilton	Shelby	Linn
3	over 1,500	paved	$32,877	$32,877	$38,892
4	400-1,500	paved	30,094	30,094	35,583
5	under 400	paved	25,881	25,881	30,684
6	over 100	gravel	17,454	17,454	20,656
7	25.1-100	gravel	6,621	6,621	7,764
8	0-25	dirt	4,213	4,213	4,899

Table 47. Reconstruction costs per lane mile of road by road surface, traffic level and highway group, 1982.

Highway group number	ADT group	Surface type	Study area		
			Hamilton	Shelby	Linn
3	over 1,500	paved	$183,867	$263,684	$307,642
4	400-1,500	paved	123,505	165,865	193,695
5	under 400	paved	58,141	73,092	85,659
6	over 100	gravel	26,121	36,088	42,179
7	25.1-100	gravel	12,399	19,043	22,113
8	0-25	dirt	7,824	11,977	13,867

cost of paved and gravel roads were represented by highway group numbers 5 and 8. The slope was calculated between each of the midpoints. The revised reconstruction and resurfacing cost equations are shown in Tables 48 and 49.

Long-term investments in road reconstruction, resurfacing and obliteration were annualized using the following capital recovery equation:

$$CRF = C \frac{i(1+i)^n}{(1+i)^n - 1} \tag{20}$$

where:

CRF = capital recovery factor;

C = investment cost;

n = service life;

i = interest rate.

The interest rate used in this analysis was a real interst rate obtained by subtracting the 1982 inflation rate of six percent from the nominal interest rate on high grade municipal bonds of 11.57 percent. Thus, the real interest rate used to obtain the capital recovery on road investment costs was 5.6 percent.

Table 48. Resurfacing cost equations per lane mile of road by road surface, traffic level and study area.

ADT group	Surface	County	Resurfacing cost equations	
Over 1,500	paved	Hamilton	W = $1.21Z + $30,094	
		Shelby	W = 1.21Z + 30,094	where Z = ADT-950
		Linn	W = 1.44Z + 35,583	
400 - 1,500	paved	Hamilton	W = 7.66Z + 25,881	
		Shelby	W = 7.66Z + 25,881	where Z = ADT-400
		Linn	W = 8.91Z + 30,684	
under 400	paved	Hamilton	W = 25,881	
		Shelby	W = 25,881	
		Linn	W = 30,684	
over 100	gravel/	Hamilton	W = 57.78Z + 6,621	
	dirt	Shelby	W = 57.78Z + 6,621	where Z = ADT-62.50
		Linn	W = 68.76Z + 7,764	
25.1-100	gravel/	Hamilton	W = 64.21Z + 4,213	
	dirt	Shelby	W = 64.21Z + 4,213	where Z = ADT-25
		Linn	W = 76.40Z + 4,899	
0-25	gravel/	Hamilton	W = 4,213	
	dirt	Shelby	W = 4,213	
		Linn	W = 4,899	

Table 49. Reconstruction cost equations per lane mile of road by road surface, traffic level and study area.

ADT group	Surface	County	Reconstruction cost equations	
Over 1,500	paved	Hamilton	Y = $26.24Z + $123,505	
		Shelby	Y = 42.53Z + 165,865	where Z = ADT-950
		Linn	Y = 49.54Z + 193,695	
400.1-1,500	paved	Hamilton	Y = 118.84Z + 58,141	
		Shelby	Y = 168.68Z + 73,092	where Z = ADT-400
		Linn	Y = 196.43Z + 85,659	
under 400	paved	Hamilton	Y = 58,141	
		Shelby	Y = 73,092	
		Linn	Y = 85,659	
over 100	gravel/	Hamilton	Y = 73.18Z + 12,399	
	dirt	Shelby	Y = 90.91Z + 19,043	where Z = ADT-62.50
		Linn	Y = 107.02Z + 22,113	
25.1-100	gravel/	Hamilton	Y = 122.00Z + 7,824	
	dirt	Shelby	Y = 188.43Z + 11,977	where Z = ADT-25
		Linn	Y = 219.89Z + 13,867	
0-25	gravel/	Hamilton	Y = 7,824	
	dirt	Shelby	Y = 11,977	
		Linn	Y = 13,867	

APPENDIX C

PROCEDURE FOR ESTIMATING VEHICLE TRAVEL COSTS ON PAVED, GRANULAR AND EARTH SURFACE ROADS

Each vehicle was classified as either a road vehicle or a farm vehicle. Road vehicles include automobiles, pickups, commercial vans, and semitrailer trucks, garbage trucks, school buses, farmer-owned single axle, tandem axle and semitrailer trucks. Farm vehicles include farm tractors and combines which are designed primarily for field work purposes. After accounting for the various vehicles pulling different types of equipment, variable costs are estimated for 13 types of road vehicles and 21 types and sizes of farm vehicles. The following is a summary of the procedures used to estimate each cost component.

Fuel Costs

Fuel cost in cents per mile for each vehicle type was estimated as:

$$F_i = \left[FP_i\right]\left[FC_i\right]^{-1} \tag{21}$$

where:

F_i = fuel cost in cents per mile for vehicle type i;

FP_i = fuel price in cents per gallon for vehicle type i;

FC_i = fuel consumption in miles per gallon for vehicle type i;

For farm vehicles, fuel consumption in miles per gallon is defined as the ratio of speed in miles per hour divided by fuel consumption in gallons per hour or:

$$FC_i = \left[S_i\right]\left[G_i\right]^{-1} \tag{22}$$

where:

S_i = speed in miles per hour for farm vehicle type;

G_i = fuel consumption in gallons per hour for farm vehicle type i. Behavioral relationships between G_i and the percent engine load for vehicle type i (EL_i) were estimated using least squares regression procedures and are used to estimate G_i for each vehicle type. The estimate for EL_i is obtained from (23):

$$EL_i = V_i + \frac{(D_i * S_i)}{375} \tag{23}$$

where:

V_i = percent of engine load for vehicle i with no trailing equipment or wagons;

V_i = 30 percent on gravel roads at 10 m.p.h.,

V_i = 40 percent on paved roads at 11 m.p.h.

D_i = the draft of vehicle type i is defined in (24):

$$= C_i * A_i \tag{24}$$

where:

C_i = adjustment coefficient to convert the weight of equipment being pulled by vehicle type i on a specified surface type to vehicle draft;

A_i = weight of the equipment being pulled by vehicle type i obtained from (23).

Oil Costs

Oil cost in cents per mile for each vehicle type was calculated as follows:

$$O_i = OP_i * OC_i \tag{25}$$

where:

O_i = oil cost in cents per mile for vehicle type i;

OP_i = oil price per unit for vehicle type i;

OC_i = oil consumption in quarts per mile for road vehicle type i. For farm vehicle type i, oil consumption in gallons per mile is defined as (26):

$$= \left[OM_i\right] \left[S_i\right]^{-1} \tag{26}$$

where:

OM_i = oil consumption in gallons per hour for farm vehicle type i was taken directly from the 1981 Agricultural Engineering Yearbook and is defined as:

$$= 0.00573 + 0.00021\ H_i \tag{27}$$

where:

H_i = engine horsepower for farm vehicle type i;

S_i = speed in miles per hour for farm vehicle type i.

Tire Costs

Tire cost in cents per mile for each vehicle type was estimated as follows:

$$T_i = \left[N_{ik} * TP_{ik}\right] L_{ik}^{-1} \tag{28}$$

where:

T_i = tire cost in cents per mile for vehicle type i;

k = type of tire (i.e. front, rear, trailer tires);

N_{ik} = number of the tire type k on vehicle type i;

TP_{ik} = price of tire type k for vehicle type i;

L_{ik} = expected life in miles of tire type k for road vehicle type i;

For farm vehicle type i, the expected life in miles of tire type k is defined as:

$$L_{ik} = M_{ik} * S_i \tag{29}$$

where:

M_{ik} = expected life in hours of tire type k for vehicle type i;

S_i = speed in miles per hour for vehicle type i.

Maintenance Costs

Maintenance and repair cost in cents per mile for road vehicles were taken from previous studies whenever possible. In those cases

where maintenance and repair cost for road vehicles were not available, maintenance costs for vehicle type i were estimated by:

$$MC_i = \overline{R_i} \left[\overline{AM_i} \right]^{-1} \tag{30}$$

where:

MC_i = maintenance and repair cost in cents per mile for vehicle type i;

$\overline{R_i}$ = average annual maintenance and repair cost in cents for road vehicle type i;

$\overline{AM_i}$ = average annual miles driven by road vehicle type i.

Maintenance and repair cost in cents per mile for farm vehicle type i was estimated by:

$$MC_i = R_i \left[AM_i \right]^{-1} \tag{31}$$

where:

R_i = estimated total lifetime maintenance and repair cost for farm vehicle type i. The 1981-1982 Agricultural Engineers Handbook estimates R_i to be (32):

$$= (0.120)\ (VP_i)\ (Q_i/1000)^{2.033} \tag{32}$$

AM_i = total lifetime miles for farm vehicle type i and is estimated by (33):

$$= Q_i * S_i \tag{33}$$

where:

R_i = total lifetime repairs in cents for vehicle type i;

VP_i = list price of vehicle type i;

Q_i = estimated life in hours for vehicle type i;

S_i = speed in miles per hour for vehicle type i.

Travel Time Component

Variable travel time cost in cents per mile for each vehicle type was calculated as:

$$TT_i = (NA_i * W_i)\ (S_i)^{-1} \tag{34}$$

where:

TT_i = travel time cost in cents per mile for vehicle type i;

NA_i = the average number of adults in vehicle type i;

W_i = the estimated value of the adults' time in cents per hour for vehicle type i;

S_i = the speed in miles per hour of vehicle type i.

Table 50 presents the estimated travel time costs per mile for registered vehicles. The hourly wage rate used for a farm tractor and combine driver was $7.00 per hour.

Table 50. Estimated time value in cents per mile for registered vehicles.

Vehicle	Time value in cents per mile
Automobile	9.8
Pickup truck	9.6
Commercial van	21.5
Commercial semitrailer truck	21.5
Garbage truck	29.4
School bus	10.0
Farmer-owned single axle truck	10.8
Farmer-owned tandem truck	10.8
Farmer-owned semitrailer truck	10.8

Variable Costs by Surface Type

The fuel, oil, tire, maintenance, and travel time cost components were estimated for each road vehicle and then summed to arrive at a "base" variable cost function, reflecting the surface combination which corresponds to the data used to develop the cost functions. The surface combination for the school bus variable cost estimate was 43 percent paved, 50 percent gravel, and seven percent earth surface travel. The farmer-owned single axle, tandem axle, and semitrailer surface combination was assumed to be 50 percent paved and 50 percent gravel surface travel. The remaining road vehicles "base" variable cost estimates were assumed to have 100 percent of travel on paved surfaces. Each base variable cost function was then adjusted to paved, gravel,

and earth surface variable cost functions by using Winfrey's 40 mile per hour surface adjustment factors.

Winfrey's surface adjustment factors reflect the changes in variable running cost that occur due to changes in surface types. These variable cost changes are the result of characteristics of the road surface such as firmness, abrasiveness, roughness, dustiness and looseness of the surface. Winfrey's adjustment factors include fuel, oil, tires, maintenance and depreciation. The travel time cost component was also included in the adjustment factors because of the speed differentials on different surface types.

Winfrey only provided surface adjustment factors for road vehicles. Consequently, the fuel, oil, tire, maintenance, and travel time costs for farm vehicles were estimated for each type of vehicle on both paved and gravel surfaces. The impact of surface type on variable costs is reflected in the estimated speed, engine load, including draft, and tire wear. The estimated cost components were then summed by surface type to arrive at variable cost functions for each farm vehicle on paved and gravel surfaces. The resulting costs per vehicle mile are presented in Table 36.

APPENDIX D

TRAVEL TIME PENALTY

Some farm equipment travel resulting from a change in the road system has an extra cost in addition to the usual fuel, tire wear, labor, oil and maintenance costs. Farmers will incur an opportunity cost from the increased travel time if the extra travel time prevents finishing the planting or harvesting of a crop in the optimal time period. If, for example, a field could not be planted in one day and overnight the weather changed to rain, several days may pass before planting is completed. Assuming a corn crop and an initial planting date of May 14, a two-day delay in planting can reduce yield by approximately 1.6 percent [Edwards and Boehlje, 1980]. Assuming a 100-bushel per acre yield with a corn price of $2.50 per bushel, a two-day planting delay would cost $4 per acre. Thus, when a farmer is forced to travel longer because of a change in the road system, a travel time penalty is incurred.

When faced with increased travel time, a farmer can minimize his losses by several strategies including:

1. Allow the yield to decline--called timeliness loss.
2. Work longer hours.
3. Change the crop mix.
4. Farm fewer acres.
5. Increase the size of his machinery--called machine capacity.

Predicting the cost of implementing any of the five strategies should give an estimate of the travel time penalty.

In this study, the travel time penalty cost is based on the cost for increasing machine capacity to permit the farmer to operate the same amount of land in the same total time as before the change in the road system. For example, of the farmer spends an extra 10 minutes on the road machine capacity is increased enough to allow the same amount of acres to be covered in ten fewer minutes.

Estimating Increased Machinery Capacity

The amount of increased machinery capacity can be estimated by using measures of effective field capacity and road speed. The effective capacity for a machine is the estimated number of acres a given machine can cover in one hour. For example, a 4-row, 30 inch planter has an estimated field capacity of 4.6 acres/hour [PM 696, ISU Extension Service].

Assuming a farmer maintains an average road speed of 10 m.p.h. on a gravel road, an extra mile traveled on gravel requires six additional minutes. If the farmer gives up six minutes of field time because of one additional mile of travel, then his machine capacity must increase enough to cover the same ground in six less minutes.

The change in machine capacity per extra mile traveled can be represented by the following equations:

$$\Delta A_{ijk} = [MC_j]\ [MPH_{jk}]^{-1} \tag{35}$$

where:

ΔA_{ijk} = the change in acres per extra mile traveled which farmer i must cover with increased machine capacity for the jth machine on the kth surface type to compensate for the extra road mile traveled.

MC_j = the machine capacity in acres per hour for the jth machine;

MPH_{jk} = the speed in miles per hour of the jth machine on the kth road surface type, and with the following:

$$\Delta C_{ijk} = \frac{\Delta A_{ijk}}{Y_{ij}} \tag{36}$$

where:

ΔC_{ijk} = the change in capacity required per extra mile traveled for farmer i using machine j on the kth surface type;

Y_{ij} = the total work time of farmer i where work time is the total of travel and field time, using machine j on surface type k.

The percent change in capacity required is estimated by (37):

$$PCC_{ijk} = \frac{\Delta C_{ijk} * 100}{CC_{ij}} \tag{37}$$

where:

PCC_{ijk} = the percent change in machine capacity required per extra mile traveled by farmer i, using machine j on surface type k;

CC_{ij} = the total machine capacity of farmer i, defined by $\frac{A_{ij}}{Y_{ij}}$, where A_{ij} is the total area farmed by i, and Y_{ij} is the total work time of farmer i, using machine j.

PCC_{ijk} can also be written as the following:

$$PCC_{ijk} = \left[\frac{\Delta A_{ijk}}{Y_{ij}}\right]\left[\frac{Y_{ij}}{A_{ij}}\right] = \frac{\Delta A_{ijk}}{A_{ijk}} \tag{38}$$

Field Capacity Calculations

The harvesting, planting and tillage operations were the only field operations considered as time-critical. The effective field capacities for different sizes of farm equipment used in these operations are presented in Table 51. Average machine capacities are shown in Table 52.

The planters' machine capacities were combined because the farm travel questionnaire data did not separate planter trips by planter size. A weighted average planter field capacity was estimated using weights based on judgement of an Iowa State University agricultural

Table 51. Estimated machine field capacities.

Machine	Effective field capacity in acres per hour
4-row, 30 inch planter	4.6
6-row, 30 inch planter	6.7
8-row, 30 inch planter	8.7
2-row, 38 inch combine	1.5
4-row, 30 inch combine	2.3
6-row, 30 inch combine	3.2
8-row, 30 inch combine	3.9
5-foot offset disk	6.6

SOURCE: Estimating Field Capacity of Farm Machines, PM-696, August 1976, Cooperative Extension Service, Iowa State University.

Table 52. Machine field capacities for tillage, planting and harvesting, averaged over sizes of machines.

Machine	Effective field capacity in acres per hour
Planter	6.7
2 row combine	1.5
4 row combine	2.3
6-8 row combine	3.5
Disk	6.6

engineer. The weights are essentially representative of the number of each planter size used by farmers. Except for differentiating between 6- and 8-row combines, combine sizes were known from the questionnaire data. Therefore, separate field capacities were used for 2, 4 and 6-8 row combines.

Using equation (38), the percent change in machinery required to compensate for the time lost in each extra mile traveled on paved and gravel surfaces were estimated for five farm sizes. Five farm sizes were used, and were taken from the Iowa Farm Business Association [Iowa Farm Business Association, Averages for the Year 1982, Grain, April 29, 1983]. The average rotated acres and range of acres of the five farm sizes are as follows:

Average rotated acres	Range of acres
147	0-179
202	180-259
298	260-359
398	360-499
736	500+

The percent change in capacity for the five machines and five farm sizes are presented in Table 53. The estimated percent changes in capacity required for each additional mile of travel are based on a speed of 11 miles per hour on paved roads and 10 miles per hour on gravel roads.

Table 53. Percent change in capacity required for each mile traveled on paved and gravel surfaces for five farm sizes by type of equipment.

Farm size in acres	Type of equipment									
	Planter		Disk		2-row combine		4-row combine		6-8 row combine	
	Paved	Gravel	Paved	Gravel	Paved	Gravel	Paved	Gravel	Paved	Gravel
0-179	0.41	0.46	0.41	0.45	0.09	0.10	0.15	0.16	0.22	0.24
180-259	0.30	0.33	0.30	0.33	0.07	0.07	0.11	0.11	0.16	0.18
260-359	0.20	0.22	0.20	0.22	0.05	0.05	0.07	0.08	0.11	0.12
360-499	0.15	0.17	0.15	0.17	0.03	0.04	0.05	0.06	0.08	0.09
500+	0.08	0.09	0.08	0.09	0.02	0.02	0.03	0.03	0.04	0.05

The data estimates in Table 53 indicate that smaller farms require a larger percentage increase in capacity per additional mile traveled than larger farms. The reason is that small farms use smaller equipment than large farms and thus require a larger percentage increase in capacity to offset travel time on roads.

The cost of this increased capacity was based on the relationship between the cost of changing the effective field capacity and percent change in machinery fixed cost. That is, the cost of increasing machine capacity was estimated by a percent change in fixed cost.

The assumption underlying this proposed relationship is that variable costs essentially remain constant with an increase in machine capacity. Labor does not change because the farmer is spending the same amount of total time; with an increase in travel time he just spends more time on the road and less in the field. Changes in other field-time related variable costs, such as fuel consumption, are small.

Moreover, the additional wear on the equipment and fuel use because of extra road travel is taken into account by the variable running costs described in Appendix C.

The relationship between percent change in field capacity and percent change in fixed cost was estimated from data obtained from a recent analysis of farm machinery cost in central Iowa [Fulton]. This analysis provides values for fixed cost relative to hours of annual use for different machine/tractor combinations. The percent change in capacity was estimated by the following equation:

$$PCC = \frac{S_1 - S_2}{S_2} * 100 \tag{39}$$

where:

PCC = percent change in capacity;

S_1 = size of machine 1;

S_2 = size of machine 2;

The relationship between annual fixed cost and percent change in capacity was estimated by equation (40):

$$C_{ij} = b_j(PCC_{ij}) \tag{40}$$

where:

C_{ij} = the cost of increasing machine capacity, using machine j, predicted by PCC_{ij}.

Equation (40) was estimated for a planter, combine and disk. Data were not available for other tillage equipment so the disk was assumed to be representative of other tillage machines. The slopes (b_j), and R^2's for each regression are presented in Table 54.

Table 54. Slopes and R^2 of the linear regressions relating percent change in fixed cost to percent change in capacity.

Machine	R_2	Slope
Planter	0.75	1.31
Combine	0.71	0.46
Disk	0.96	1.79

None of the intercepts were significantly different from zero. All slopes were significant at the 0.0001 level.

Fixed Cost Calculations

The values of the fixed cost for each machine size were used to calculate an average fixed cost per machine. The values and the average fixed cost per machine are presented in Table 55.

Cost Per Mile Calculations

A travel time penalty cost per mile for different types of farm equipment for the five farm sizes was calculated using the relationship for percent change in fixed cost and percent change in capacity. The results of these calculations are presented in Table 56 for paved and gravel surfaces.

The data from the farm questionnaire only identified the number of trips for tractors pulling farm equipment. These trips included both disks and planters. An extension publication, "Estimated Cost of Crop Production in Iowa", was used to estimate the number of field trips attributable to tillage versus planting. Assuming a 50 percent corn

Table 55. Annual fixed machinery cost by machine size and average annual fixed cost by type of machine.

Machine type and size	Annual machine fixed cost in dollars	Average annual machine fixed cost
Disk		
10 feet	$ 316	
14 feet	462	
18 feet	604	
22 feet	1,000	
26 feet	1,208	
30 feet	1,425	$835.33
Planter		
4-38 inch rows	779	
6-30 inch rows	1,114	
6-38 inch rows	1,236	
8-30 inch rows	1,463	
8-38 inch rows	1,519	
12-30 inch rows	2,491	1,433.67
Two-row combine		
2-38 inch rows	3,642	3,642.00
Four-row combine		
4-30 inch rows	6,141	
4-38 inch rows	6,198	6,169.50
Six-eight row combine		
6-30 inch rows	7,424	
6-38 inch rows	7,574	
8-30 inch rows	7,920	7,639.33

Table 56. Percent change in capacity and fixed cost by farm size and road surface, annual fixed cost by type of machine and time penalty cost per mile by farm machine, farm size and road surface.

Machine	Farm size (acres)	Percent change in capacity		Percent change in fixed cost		Annual fixed cost	Fixed cost per mile travelled	
		Paved	Gravel	Paved	Gravel		Paved	Gravel
Disk	147	0.41	0.45	0.73	0.81	$835.33	$6.10	$6.77
	202	0.30	0.33	0.54	0.59	835.33	4.51	4.93
	298	0.20	0.22	0.36	0.39	835.33	3.01	3.26
	398	0.15	0.17	0.27	0.30	835.33	2.26	2.51
	736	0.08	0.09	0.14	0.16	835.33	1.17	1.34
Planter	147	0.41	0.46	0.54	0.60	1,433.67	7.74	8.60
	202	0.30	0.33	0.39	0.43	1,433.67	5.59	6.16
	298	0.20	0.22	0.26	0.29	1,433.67	3.73	4.16
	398	0.15	0.17	0.20	0.22	1,433.67	2.87	3.15
	736	0.08	0.09	0.10	0.12	1,433.67	1.43	1.72
2-row combine	147	0.09	0.10	0.04	0.05	3,642.00	1.46	1.82
	202	0.07	0.07	0.03	0.03	3,642.00	1.09	1.09
	298	0.05	0.05	0.02	0.02	3,642.00	0.73	0.73
	398	0.03	0.04	0.01	0.02	3,642.00	0.36	0.73
	736	0.02	0.02	0.01	0.01	3,642.00	0.36	0.36
4-row combine	147	0.15	0.16	0.07	0.07	6,169.50	4.32	4.32
	202	0.11	0.11	0.05	0.05	6,169.50	3.08	3.08
	298	0.07	0.08	0.03	0.04	6,169.50	1.85	2.47
	398	0.05	0.06	0.02	0.03	6,169.50	1.23	1.85
	736	0.03	0.03	0.01	0.01	6,169.50	0.62	0.62
6-8 row combine	147	0.22	0.24	0.10	0.11	7,639.33	7.64	8.40
	202	0.16	0.18	0.07	0.08	7,639.33	5.35	6.11
	298	0.11	0.12	0.05	0.06	7,639.33	3.82	4.58
	398	0.08	0.09	0.04	0.04	7,639.33	3.06	3.06
	736	0.04	0.05	0.02	0.02	7,639.33	1.53	1.53

and 50 percent soybean crop mix, approximately one planting trip is made per 2.5 tillage trips. The disk and planter costs per mile were then weighted accordingly.

The travel time penalty costs were then combined into an average cost over all sizes of farms. A frequency distribution was run on the farm sizes from the questionnaire data from the three study areas. The time penalty costs per mile for the five farm sizes were combined into one number based on the farm size frequencies. Table 57 contains the frequency and percents for the farm size ranges.

Table 57. Number and percent of farms by farm size in the three study areas.

Farm size in acres	Number of farms	Percent of farms
0-179	185	27.53
180-259	107	15.92
260-359	86	12.80
360-499	109	16.22
500+	185	27.53

Table 58 contains the estimated travel time penalty costs. The time penalty cost is significantly higher for planter/tillage equipment than for combines. The planter/tillage combination has a much higher capacity per acre or per given time period which causes the cost of losing field time to be much higher.

Table 58. Estimated travel time penalty cost per mile by type of farm machinery and road surface in dollars per mile.

Machine	Paved	Gravel
Planter/tillage	$3.72	$4.13
2-row combine	0.83	0.99
4-row combine	2.29	2.47
6-8 row combine	4.36	4.79

Applying the Travel Time Penalty

The travel time penalty was charged only to tillage/planting and combining operations. The concept of a travel time penalty is related to a possible yield loss from not finishing field operations in an optimal time period. The travel time penalty was applied only to the change in planter/tillage and combine travel miles resulting from changes in the road system. The last trip back from the field was not charged a penalty. Once the operation is complete, the only cost for traveling was assumed to be the variable cost on the tractor, equipment and combine.

APPENDIX E

COPIES OF THE FARM AND NON-FARM QUESTIONNAIRES

February 1983

Form IV

FARM QUESTIONNAIRE

Department of Economics
and
Statistical Laboratory
Iowa State University

Rural Road Use Study

Household ID: __ __ __ __ __ __ __ __
CO. TWP. SEC. H.H.

Date __ __ __ __
MO. DAY

Start time _____

Name of Respondent _____

Interviewer ID # __ __

Iowa State University appreciates your help with this study. We will be asking for information about all travel for the members of this household as well as all members of your farming operation. We are interested in road and vehicle usage. Your responses will be kept confidential and will be released as statistical summaries only. If a question seems unclear, let me know and I will try to clarify it. If you feel a question is too personal, you have a right to refuse to answer. Let's begin with some general information about your farming operation in 1982.

[HAND R STUDY AREA MAP AND YELLOW MARKER. INDICATE TO R THE LOCATION OF HOMEBASE]

1. Would you look at this map of a portion of your county. Here is the exact location of your home. Would you please draw the approximate boundaries of the land that makes up this home tract.

[NUMBER THIS TRACT 1]

2. In 1982, how many different tracts, including your home tract, did you operate on your own, in partnership or in a corporation?

____ [IF ONE, GO TO Q. 4a]

[A TRACT IS A UNIT OF LAND SEPARATED BY A ROAD OR OTHER LAND NOT OPERATED. IF THE LAND IS ADJACENT OR NOT SEPARATED, THIS SHOULD BE ONE TRACT]

3. Now we would like you to identify the other tracts you operated in 1982. Let's begin with the tracts that fall within the boundaries of this map. Please locate each of these tracts by drawing the approximate boundaries.

4a. [NUMBER EACH TRACT AND ENTER TRACT NUMBER IN COLUMN a IN THE TABLE. ASK b AND c FOR ALL TRACTS ON MAP]

b. How many acres are in tract _____? (number)

c. How many access points do you have into tract _____? (number)

[HAND R THE RED PEN]

d. With this red pen, would you place a line on the map indicating each access point (road,etc.) you have into tract _____. (number)

[IF THE NUMBER OF TRACTS OUTLINED IS LESS THAN THE NUMBER IN Q. 2, GO TO Q. 6]

5. That seems to account for all the tracts you operate, but just to double check, let me ask you, in 1982, did you operate any tracts which are not within the boundaries of this map?

_____ Yes

_____ No ——> (Q. 8a)

a Tract number	b No. of acres	c Number of access points
1	_____ acres	_____
_____	_____ acres	_____
_____	_____ acres	_____
_____	_____ acres	_____
_____	_____ acres	_____
_____	_____ acres	_____
_____	_____ acres	_____
_____	_____ acres	_____
_____	_____ acres	_____
_____	_____ acres	_____

6. Now we would like some information about each tract you operated which is outside the boundaries of this map. Would you put an X on the border of the map which represents approximately where each tract is located.

[NUMBER CONSECUTIVELY EACH OF THESE TRACTS AND ENTER THE NUMBERS IN COLUMN a. ASK b THROUGH f FOR EACH]

7a. I'd like to get some information about each of these tracts. Let's begin with tract _____.
(number)

b. In what county is this tract located?

c. In what township is this tract located?

d. What section is this tract in?

e. Where in the section is the tract located?

f. How many acres are in this tract?

a Tract number	b County	c Township	d Section number	e Where in section [e.g. NE corner]	f Number of acres

8a. In 1982, did you operate any of the tracts we have talked about with another farmer (in partnership, corporation, etc.)?

_____ Yes
_____ No (Q. 9)

[FOR OUR PURPOSES, A PARTNERSHIP IS AN INFORMAL OR FORMAL ARRANGEMENT WHERE TWO OR MORE FARMERS SHARE THE WORK OR LABOR IN A FARMING OPERATION]

b. What is the other farmer's name?

_____

c. Does _____ live within the boundaries of this map?
(name)

_____ Yes
_____ No (Q. 8e)

d. Place an X on the map to indicate where he lives.

[ON THE MAP, IDENTIFY THIS LOCATION AS "PARTNER" AND GO TO Q. 9]

e. Could you give me the exact location of your partner's home. [PROBE FOR LEGAL DESCRIPTION OR DIRECTION]

_____

_____

9. Now we would like you to think of the products that were either delivered to you or picked up by a member of your farming operation in 1982. We will only record information for products brought to tracts within the boundaries of the map.

[ASK a FOR ALL PRODUCTS]

a. In 1982 was _____ (product) brought to any of these tracts? [IF NO, GO TO NEXT PRODUCT]

b. Did you usually take a full truck load?

c. To which tracts was _____ (product) delivered?

d. During 1982, how many times was _____ (product) delivered to tract _____ (number)?

[HAND R THE GREEN CARD]

e. Looking at the green card which lists various types of delivery vehicles, tell me the code number for the type of vehicle which usually delivered the _____ (product)?

[PROBE FOR NUMBER OF TRIPS WITH DIFFERENT VEHICLES OR TO SEVERAL LOCATIONS]

f. What is the name and location of the dealer who delivered the _____ (product)?

Product	a Delivered?		b Full?		c & d								e	f
	Yes	No	Yes	No	Tract no.	Number of times	Tract no.	Number of times	Tract no.	Number of times	Tract no.	Number of times	Type of vehicle	Dealer & location
Diesel fuel or gasoline	1	2	1	2	___	___	___	___	___	___	___	___		
					___	___	___	___	___	___	___	___		
LP gas (propane) or fuel oil	1	2	1	2	___	___	___	___	___	___	___	___		

Anhydrous ammonia or other liquid fertilizer	1	2	1	2	— — — —	— — — —	— — — —	— — — —		
					— — — —	— — — —	— — — —	— — — —		
Dry fertilizer	1	2	1	2	— — — —	— — — —	— — — —	— — — —		
Herbicides/ Insecticides	1	2	1	2	— — — —	— — — —	— — — —	— — — —		
Seed, feed	1	2	1	2	— — — —	— — — —	— — — —	— — — —		
					— — — —	— — — —	— — — —	— — — —		
Livestock (Type?) _____	1	2	1	2	— — — —	— — — —	— — — —	— — — —		
Water	1	2	1	2	— — — —	— — — —	— — — —	— — — —		
					— — — —	— — — —	— — — —	— — — —		
Any other deliveries (Specify) _____	1	2	1	2	— — — —	— — — —	— — — —	— — — —		

10a. In 1982, did you take any equipment which was more than 16 feet wide on county roads? (Ex. a planter, combine, cultivator)

_____ Yes

_____ No (Q. 11a)

b. What type of equipment was that?

_____

_____

_____

_____

c. What was the width of this equipment when traveling on county roads?

_____ ft. wide

11a. Please think about all the vehicles and farm equipment that you or other members of your farming operation drove on the county roads in the study area. In 1982, did you ever take an alternate route _____?
(reason)

[IF YES, ASK b AND c]

b. With what equipment or vehicles did you take an alternate route _____?
(reason)

[HAND R THE BLUE MARKER AND MAP]

c. We are going to call this route _____. Using this marker, would
(letter from c)

you draw the route you took _____?
(reason)

[REPEAT a THROUGH c FOR ALL REASONS]

Reason	a Take Yes	a Take No	b What equipment	c Route letter
because of narrow bridges	1	2		A
because of weight limits on bridges	1	2		B
because of weight limits on roads	1	2		C
because of dirt roads	1	2		D
to avoid heavy traffic on roads	1	2		E
to use gravel roads with a tractor	1	2		F
to avoid gravel roads with a car	1	2		G
for any other reason _____ (Specify)	1	2		H

[HAND R THE WHITE CARD]

12. Now we'd like you to think about the use of pickup trucks on your farm. Would you look at the white card which lists reasons a pickup might be used. Keeping these reasons in mind, we'd like you to think about how often you or other members of your farming operation traveled with a pickup on county roads to <u>each</u> tract you operated.

[ASK a THROUGH e FOR EACH TRACT R OPERATES]

a. In 1982, during the winter months, how often did someone go to tract _____ (number) with a pickup?

b. In 1982, during the spring months, how often did someone go to tract _____ (number) with a pickup?

c. In 1982, during the summer months, how often did someone go to tract _____ (number) with a pickup?

d. In 1982, during the fall months, how often did someone go to tract _____ (number) with a pickup?

e. When you traveled to tract _____ (number), generally, which tract were you coming from?

	a Winter		b Spring		c Summer		d Fall		e
Tract number	No. of times	Frequency	No. of times	Frequency	No. of times	Frequency	No. of times	Frequency	From which tract?
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	___ ___
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	___ ___
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	___ ___
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	___ ___
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	___ ___
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	___ ___
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	___ ___
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	___ ___
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	___ ___
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	___ ___

13. Still thinking about your pickup, now we'd like to know all of the places you traveled off the farm with this vehicle for farm business or activities.

a. In 1982, to what cities, towns or locations did you or other members of your farming operation travel with a pickup to do farm business?

[DO NOT INCLUDE HAULING PRODUCTS HERE - THEY WILL BE RECORDED LATER]

[ASK b THROUGH e]

b. In the winter months, how often did someone go to _____ (location) with a pickup to do farm business?

c. In the spring months, how often did someone go to _____ (location) with a pickup to do farm business?

d. In the summer months, how often did someone go to _____ (location) with a pickup to do farm business?

e. In the fall months, how often did someone go to _____ (location) with a pickup to do farm business?

f. Thinking of all the trips made with a pickup to _____ (location), what percent were from tract 1?

[REPEAT FOR EACH CITY, TOWN, LOCATION]

a	b Winter		c Spring		d Summer		e Fall		f Percent from tract 1
City, town location	No. of times	Frequency	No. of times	Frequency	No. of times	Frequency	No. of times	Frequency	
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	__ __ __
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	__ __ __
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	__ __ __
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	__ __ __
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	__ __ __
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	__ __ __
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	__ __ __
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	__ __ __
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	__ __ __
	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	______	D W M SEA.	__ __ __

14. [HAND R THE PINK CARD]

Listed on the pink card are types of farm vehicles. We want to know about the use of vehicles like these on your farm. Would you think about all of the vehicles used for activities you engage in from spring tillage through fall field work. Do not include grain hauling or the use of the pickups since we are recording those trips elsewhere. We will record trips with these vehicles to all tracts, but only want to consider trips if the vehicle traveled on county roads.

[ASK FOR ALL VEHICLES]

a. In 1982, was a _____ (vehicle type) used on your farm and driven on county roads?

[IF YES, ASK b THROUGH d]

b. Where did this _____ (vehicle) come from?

[ASK c AND d FOR EACH TRACT VEHICLE CAME FROM]

c. To which tracts did the _____ (vehicle) go?

[ASK FOR EACH ROUTE INDICATED IN b AND c]

d. How many times was that trip taken?

[REPEAT FOR EACH VEHICLE TYPE]

Vehicle type	a Used Yes	a Used No	b Where from?	c Where to?	d No. of times	b Where from?	c Where to?	d No. of times	b Where from?	c Where to?	d No. of times
a tractor alone	1	2	___ ___	___ ___	___	___ ___	___ ___	___	___ ___	___ ___	___
			___ ___	___ ___	___	___ ___	___ ___	___	___ ___	___ ___	___

a tractor pulling farm equipment	1	2						
a pickup pulling farm equipment	1	2						
combines	1	2						
an automobile	1	2						
any other vehicles	1	2						
Specify _____								

15. Now I am going to ask several questions about your farm machinery. On which tract or tracts is most of your farm machinery kept or stored?

_____

16. How many combines did you use in 1982?

___ ___ [IF NONE, GO TO Q. 17]

a. Tell me the make and model of each combine?

b. How many rows is the cornhead?

c. What was the size of the beanhead?

a Make & model	b Cornhead	c Beanhead
	___ ___ rows	_____ ft.
	___ ___ rows	_____ ft.
	___ ___ rows	_____ ft.

17. How many tractors did you use in 1982?

_____ [IF NONE, GO TO Q. 19]

[FOR EACH TRACTOR, ASK 18a, 18b and 18c]

18. I'd like to ask some questions about each tractor you used. Let's begin with the largest tractor.

a. What is the make and model of this tractor?

b. What horsepower is this tractor?

[ASK a FOR ALL, THEN ASK b AND c FOR EACH TRACTOR]

c. Thinking of all the times someone took a tractor on county roads in 1982, what percent of the time was this tractor used?

(a) Make & model	(b) Horsepower	(c) % of time used

19. How many trucks did you or other members of your farming operation own in 1982?

___ ___ [IF NONE, GO TO Q. 24]

20. How many of these were pickups?

___ ___

21. How many of these were single-axle trucks other than a pickup?

___ ___

22. How many of these were tandem-axle trucks?

___ ___

23. How many of these were semis?

___ ___

24. Now we would like you to think about the products that were hauled from a tract to another location using county roads. This could include transporting from a field to on-farm storage, to the elevator, to market, as well as to any other location. Please include custom hauling, as well as hauling done by any other member of your farming operation. Include trips for products hauled in 1982 even if they were produced in another year.

[ENTER TRACT NUMBER IN COLUMN BELOW AND ASK ...]

a. What products were hauled from tract _____ (number) using county roads? [LIST PRODUCTS IN COL. a, THEN ASK b THRU f FOR EACH PRODUCT]

b. Approximately how many loads of _____ (product) were hauled using county roads?

c. Thinking of on-farm as well as off-farm locations, where was the _____ (product) hauled? [ASK d THRU f FOR EACH LOCATION

d. How many loads did you take to _____ (location)?

[HAND R YELLOW CARD] e. Looking at the yellow card, which lists types of hauling vehicles, would you tell me the code number for the type of vehicle used to haul the _____ (product) to _____ (location)?

f. When hauling grain, what was the average number of bushels hauled per trip to _____ (location)?

Tract number	a Product hauled	b Total no. of loads hauled	c Where to?	d No. of loads to location	e Type of vehicle	f Avg. bu. hauled
____			_____	__ __	__ __	_____
			_____	__ __	__ __	_____
			_____	__ __	__ __	_____
			_____	__ __	__ __	_____

25. In this section of the interview we would like some information about personal and family travel. First we will ask some questions about your household.

In 1982, how many people were living in this household. Include college students who may be away temporarily as well as anyone else who lives here and has no other home.

__ __

a. What is the first name of each household member? [ENTER IN COLUMN a]

[ASK b AND c FOR EACH HOUSEHOLD MEMBER]

b. What was _____ age on his/her last birthday?
(member)

c. What is _____ relationship to the head of the household?
(member)

a Household member	b Age	c Relationship
_____	__ __	_____
_____	__ __	_____
_____	__ __	_____
_____	__ __	_____
_____	__ __	_____
_____	__ __	_____
_____	__ __	_____

26. How many of these people operated a motor vehicle?

__ __

27. Next we would like some information about where household members go for various activities. We want the names of towns or cities, not the specific store, bank, etc.

a. In 1982, generally where did your family go _____? [ENTER NAME OF EACH CITY OR TOWN]
(activity)

Activity	City/town
a) to do their shopping	_____ _____ _____ _____
b) to school (preschool) or to attend school functions. Do not include rides on the school bus.	_____ _____
c) to attend church services or activities	_____
d) to attend social functions, visit friends and relatives or go for recreation	_____ _____ _____

e) to attend meetings	_____ _____
f) to do banking or other family business	_____ _____
g) to see a doctor or dentist	_____ _____
h) to work off the farm	_____ _____
i) to do any other activities not mentioned (specify what) _____	_____

[ENTER IN COLUMN a) BELOW THE NAME OF EACH TOWN OR CITY LISTED IN QUESTION 27
ASK QUESTIONS b THROUGH f FOR EACH CITY OR TOWN]

28a. Next we would like you to think about how frequently your family goes to each town or city. Please think of all household members as well as all the different reasons in order to determine how many total trips were taken. You may give your answer on a daily, weekly, monthly basis or as a total for the time period (season).

b. Thinking of the winter season, how often did household members go to _____? (city)

[ENTER NUMBER AND CIRCLE FREQUENCY]

c. During the spring season, how often did household members go to _____? (city)

d. During the summer season, how often did household members go to _____? (city)

e. During the fall season, how often did household members go to _____? (city)

[IF NO CHILDREN IN HOUSEHOLD, SKIP (f)]

f. When you go to _____, what percent of the trips you take are <u>only</u> to transport your children to and (city)

from their activities such as school, doctors, dentists and recreation?

a	b Winter		c Spring		d Summer		e Fall		f
City/Town	No. of times	Frequency	No. of times	Frequency	No. of times	Frequency	No. of times	Frequency	Percent
1.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
2.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
3.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
4.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
5.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
6.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
7.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
8.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
9.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
10.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
11.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
12.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %

[HAND R THE ORANGE CARD]

29a. Would you look at the orange card which lists products which may have been delivered to you. Thinking of any products like these, would you tell me, in 1982 did you have any of these kinds of deliveries made to your place?

____ Yes

____ No (Q. 30)

b. What types of products were delivered?

[LIST ALL IN COLUMN b AND ASK c AND d FOR EACH]

c. From what town or city was the _____ (type) delivery made?

[ASK d FOR EACH LOCATION]

d. During 1982, how many times did you have _____ (type) delivered from _____ (city)?

[ENTER NUMBER AND CHECK FREQUENCY IN COLUMN d]

(b) Type of delivery	(c) Location of dealer	(d) No. of times	Da	Wk	Mo	Yr

30. In this last section we'd like some information about people who came onto your place in 1982.

a. During 1982, did you have _____ (visitor) come to your place?

[IF YES, ASK b, c AND d]

b. To which tract did these _____ (visitors) usually come?

c. Generally, what city or town were these people coming from?

[IF RESP. CANNOT GIVE CITY OR TOWN, PROBE FOR DIRECTION]

d. During 1982, how many times did _____ (visitor) come from _____ (city) to your place? [ENTER NUMBER AND CHECK FREQUENCY COLUMN]

Type of visitor	a Have? Yes	a Have? No	b Where to (Tract no.)	c Where from? (city, town)	d No. of times	d Da	d Wk	d Mo	d Yr
Repairmen or workmen	1	2	__ __	_____	__ __				
			__ __	_____	__ __				
Salespeople	1	2	__ __	_____	__ __				
			__ __	_____	__ __				

Guests or relatives or neighbors	1	2				
Hired help such as a cleaning lady, baby-sitters or yardmen	1	2				
Veterinarian or farm hands	1	2				
Any others? [Specify who] _____	1	2				

31. We are interested in knowing what your plans are for the future.

a. Do you expect to be farming here in _____?
(time period)

[IF NO, ASK a FOR NEXT TIME PERIOD]

b. Do you plan to change the size of your farming operation in _____? [IF NO, GO TO NEXT TIME PERIOD]
(time period)

c. Would this change be an increase or a decrease?

	a Farming?		b Change size?		c How change?	
Time period	Yes	No	Yes	No	Inc.	Dec.
5 yrs.						
10 yrs.						
15 yrs.						
20 yrs.						

This completes our interview. Is there anything else you would like to tell us about your travel?

_____

_____

Iowa State University appreciates your help with this project.

Ending time ___ ___ : ___ ___

Total minutes of interview ___ ___ ___

[INTERVIEWER COMPLETE THIS PORTION AFTER LEAVING RESPONDENT'S HOME]

In general, how would you rate the reliability of the information given?

1 = very reliable
2 = generally reliable
3 = not very reliable
4 = poor

Why? _____

_____

_____

Was there anything about the respondent or interview setting which you feel affected the quality of the interview?

___ No
___ Yes ——> Explain _____

_____

_____

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January 1983
Form III
NONFARM QUESTIONNAIRE

Department of Economics
and
Statistical Laboratory
Iowa State University

Rural Road Use Study

Household ID: __ __ __ __ __ __ __ __
CO. TWP. SEC. H.H.

Date __ __ __ __
MO. DAY

Start time _____

Name of Respondent _____

Interviewer ID # __ __

Iowa State University appreciates your help with this study. We will be asking for information about all travel for the members of this household. Your responses will be kept confidential and will be released as statistical summaries only. If a question seems unclear, let me know and I will try to clarify it. If you feel a question is too personal, you have the right to refuse to answer.

I'd like to begin with some general information about your household.

1. In 1982, how many people were living in this household? Include college students who may be away temporarily, as well as anyone else who lives here and has no other home.

__ __

2a. What is the first name of each household member?

[ASK b AND c FOR EACH HOUSEHOLD MEMBER]

b. What was _____ age on his/her last birthday?
(member)

c. What is _____ relationship to the head of the household?
(member)

a Household member	b Age	c Relationship
	__ __	
	__ __	
	__ __	
	__ __	
	__ __	
	__ __	
	__ __	
	__ __	

3. How many of these people operated a motor vehicle?

__ __

4. Now we would like some information about where household members go for various activities. We want the names of towns or cities, not the specific store, bank, etc.

In 1982, generally where did your family go _____? [ENTER NAME OF EACH CITY OR TOWN]
(activity)

Activity	City/town
a) to do their shopping	_____
	_____
	_____
	_____
b) to school (preschool) or to attend school functions	_____
	_____
c) to attend church services or activities	_____
d) to attend social functions, visit friends and relatives or go for recreation	_____
	_____
	_____
e) to attend meetings	_____
	_____
f) to do banking or other family business	_____
	_____
g) to see a doctor or dentist	_____
	_____
h) to work	_____
	_____
i) to do any other activities not mentioned (specify what) _____	_____

[ENTER IN COLUMN a) BELOW THE NAME OF EACH TOWN OR CITY LISTED IN QUESTION 4
ASK QUESTIONS b THROUGH f FOR EACH CITY OR TOWN]

a. Next we would like you to think about how frequently your family goes to each town or city. Please think of all household members as well as all the different reasons in order to determine how many total trips were taken. You may give your answer on a daily, weekly, monthly basis or as a total for the time period (season).

b. Thinking of the winter season, how often did household members go to _____? (city)

[ENTER NUMBER AND CIRCLE FREQUENCY]

c. During the spring season, how often did household members go to _____? (city)

d. During the summer season, how often did household members go to _____? (city)

e. During the fall season, how often did household members go to _____? (city)

[IF NO CHILDREN IN HOUSEHOLD, SKIP (f)]

f. When you go to _____, what percent of the trips you take are only to transport your children to and (city)

from their activities such as school, doctors, dentists and recreation?

a	b Winter		c Spring		d Summer		e Fall		f
City/Town	No. of times	Frequency	No. of times	Frequency	No. of times	Frequency	No. of times	Frequency	Percent
1.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
2.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
3.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
4.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
5.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
6.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
7.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %
8.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	_____	D W M SEA.	___ ___ ___ %

6. We are interested in the types of vehicles household members used in 1982. These may be vehicles owned by others and used by household members for work (etc.) as well as your own vehicles.

a. How many automobiles did household members drive to and from this place in 1982?

___ ___

b. How many pickup trucks did household members drive to and from this place in 1982?

___ ___

[HAND R THE BLUE CARD]

c. Looking at the blue card, would you tell me, how many vehicles like these did household members drive to and from this place in 1982?

___ ___ [IF NONE, GO TO Q. 7]

d. Still looking at the card, please give me the code numbers for each vehicle driven to and from this place in 1982.

[ASK e FOR EACH VEHICLE]

e. To what cities and towns was this vehicle driven?

[ASK f FOR EACH TOWN]

f. Thinking of all the trips household members made to _____ (city/town), what percent of the time was this vehicle driven?

d Vehicle	e City/town	f Percent of times
___ ___	_____ _____	_____ _____
___ ___	_____ _____	_____ _____
___ ___	_____ _____	_____ _____

7a. [HAND R THE STUDY AREA MAP AND YELLOW MARKER]

Would you look at this map which shows a part of your county. Here is where your home is located. Draw this lot on the map.

b. How many acres is this? _____

[HAND R THE RED PENCIL]

c. With this red pencil, place a line on the map to represent each access point you have to your place.

8a. In 1982, when household members traveled to the places we have just talked about, did they usually take the shortest route?

_____ Yes (Q. 9)

_____ No ⟶ Why not? _____

_____

_____

[HAND R THE BLUE MARKER]

b. We would like to know exactly which routes were taken when people were not taking the shortest route. Using this marker, please draw each route on the map.

[IF NO TRUCKS IN Q. 6c, GO TO Q. 9]

c. With what vehicle was this route taken?

____ ____

9. In this final section we would like you to think about the traffic which came onto your place. We'll first talk about deliveries made to you.

a. In 1982, did you have any _____ delivered?
(product)

[IF YES, ASK b AND c]

b. From what town or city were deliveries made?

[ASK c FOR EACH LOCATION]

c. During 1982, how many times did you have _____ delivered from _____?
(product) (city)

[ENTER NUMBER AND CHECK FREQUENCY IN COLUMN c]

Product	a Delivered? Yes	a Delivered? No	b Location of dealer	c No. of times	Da	Wk	Mo	Yr
Diesel fuel or gasoline	1	2	_____	__ __				
			_____	__ __				
LP gas (propane) or fuel oil	1	2	_____	__ __				
			_____	__ __				

[HAND R THE ORANGE CARD]

10a. Would you look at the orange card which lists products which may have been delivered to you. Thinking of any products like these, would you tell me, in 1982 did you have any of these kinds of deliveries made to your place?

____ Yes
____ No (Q. 11)

b. What types of products were delivered?

[LIST ALL IN COLUMN b AND ASK c AND d FOR EACH]

c. From what town or city was the _____ (type) delivery made?

[ASK d FOR EACH LOCATION]

d. During 1982, how many times did you have _____ (type) delivered from _____ (city)?

[ENTER NUMBER AND CHECK FREQUENCY IN COLUMN d]

(b) Type of delivery	(c) Location of dealer	(d) No. of times	Da	Wk	Mo	Yr
		___ ___				
		___ ___				
		___ ___				
		___ ___				
		___ ___				
		___ ___				
		___ ___				
		___ ___				

11a. During 1982, did you have _____ come to your place?
(visitor)

[IF YES, ASK b AND c]

b. Generally, what city or town were these people coming from?

c. During 1982, how many times did _____ come to your place from _____?
(visitor) (city)

[ENTER NUMBER AND CHECK FREQUENCY IN COLUMN c]

Type of visitor	a Have? Yes	a Have? No	b Where from? (city, town)	c No. of times	c Da	c Wk	c Mo	c Yr
Repairmen or workmen	1	2	_____	__ __				
			_____	__ __				
Salespeople	1	2	_____	__ __				
			_____	__ __				
			_____	__ __				
Guests or relatives or neighbors	1	2	_____	__ __				
			_____	__ __				
			_____	__ __				
Hired help such as a cleaning lady, baby-sitters or yardmen	1	2	_____	__ __				
Any others? [Specify who]			_____	__ __				
_____	1	2	_____	__ __				

This completes our interview. Is there anything else you would like to tell us about your travel?

_____

_____

Iowa State University appreciates your help with this project.

Ending time ___ ___ : ___ ___

Total minutes of interview ___ ___ ___

[INTERVIEWER COMPLETE THIS PORTION AFTER LEAVING RESPONDENT'S HOME]

In general, how would you rate the reliability of the information given?

1 = very reliable
2 = generally reliable
3 = not very reliable
4 = poor

Why? _____

_____

_____

Was there anything about the respondent or interview setting which you feel affected the quality of the interview?

___ No
___ Yes ——> Explain _____

_____

_____

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