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Costs for maintaining bituminous roads, surfacing options, and benefits of bituminous roads

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Costs for maintaining bituminous roads, surfacing options, and benefits of bituminous roads

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ABSTRACT

When to upgrade an aggregate road? This is a question and decision that road governing authorities continuously ponder. In order to help in this decision process, the costs and benefits of upgrading an aggregate road to a bituminous road and costs to maintain a bituminous road need to be identified. Costs and activities performed to maintain a bituminous road are evaluated in this research to show the expected maintenance costs and key activities a governing agency in Minnesota will have to maintain various bituminous roads. These costs vary from one county to the next because of differing maintenance practices, weather and environmental conditions, and the age of the road. Based on the data, the average cost per mile to maintain a bituminous road ranges from $1900 to $4300, with an average cost of $3300. Various bituminous surfacing options currently being used in Minnesota are reviewed. Tools useful for helping to decide when to pave an aggregate road, such as a road management system and a road rating system, are also discussed. The benefits of a bituminous road, which include a reduction in maintenance activities, improved safety, and an increased tax base, are also identified.

CHAPTER 1: INTRODUCTION

Problem Statement

County and township governments in Minnesota have the responsibility of maintaining a significant portion of the roads within the state. They maintain roads ranging from simple one lane unimproved dirt roads to gravel roads to multi-lane paved highways. These roads have traffic volumes, an average daily traffic (ADT), from as low as one car per day all the way to seven thousand vehicles per day, perhaps more. The traffic being served by these roads is a result of local residents and commuters to weekend recreation trips to heavy logging and agricultural equipment and trucks. Because of the different types of road surfaces, traffic volumes, and primary traffic types, the cost to maintain a road varies from one location to the next.

A road surfaced with unbound aggregate, such as gravel, may cost x dollars per mile to maintain, while that same road surfaced with a bound, paved, surface may cost y dollars per mile to maintain. The difference between the x dollars to maintain a gravel road and y dollars to maintain a paved road is z dollars and is typically a savings to the governmental agency maintaining the road. This savings of z dollars does not necessarily out weigh the cost of the improvement to provide the road with a paved surface; however, it is a savings nonetheless. Along with the savings in maintenance costs, there are other benefits, both direct and indirect, that a county or township government experiences by upgrading the surface of their roads. The costs to maintain a road of different surface types are to some extent known by county governments, but they have never been estimated for various traffic volumes or compared with other counties. In addition, the costs to upgrade a gravel surfaced road to a paved road (i.e. one with a bound surface) are better known among local government officials, but have not been systematically recorded and analyzed. The decision about when a construction project to upgrade a road is to be performed is made many times either for political reasons or because the governmental agency was petitioned to improve the road by the residents or because traffic volumes warrant an improvement to the road. Because of these factors alone, not to mention other reasons, there are many times when a gravel road could be upgraded and there are many surface choices that could be used to upgrade the gravel road.

Since there are multiple options for upgrading an aggregate road with regard to surface types, the options for upgrading the surface should be identified and examined when deciding whether or not to upgrade an aggregate road. Estimates of the cost for maintaining a paved road should be considered. In addition, the potential benefits that result from a paved surface should be discussed. Since December 2001, Iowa State University researchers have been working with the Minnesota Department of Transportation (MNDOT) to identify the costs associated with maintaining roads at the county level and the options for upgrading those roads.

Objectives

This research looks at the costs and benefits of upgrading an aggregate road to a bound surface road, which would include concrete, bituminous, or lightly surfaced (Otta Seal, chip seal, seal coat, etc.) roads and the costs to maintain a road with hot mix asphalt (HMA). It would be desirable to estimate the costs of maintaining other surfaces; however, the number of roads with surfaces other than HMA were very limited. The costs to maintain an upgraded road will be evaluated to show the expected maintenance costs the governing agency will have after upgrading the road. Most tasks related to the maintenance of a roadway are performed without regard to the surface type present; however, all activities will be evaluated for each road surface. All the activities are being evaluated because the level of service expected from the user for any particular activity can change as the road surface changes.

Also discussed in this thesis will be a list of various options for surface improvements that are currently being and have been used by counties within Minnesota, elsewhere in the United States, and in international jurisdictions. This discussion will address surface performance and the cost of initial construction. Finally, the direct and indirect benefits the county and user receive from upgrading an unbound aggregate surfaced road to a bound surfaced (paved) road will be identified and discussed.

Thesis Organization

This chapter introduced the topic and discussed the goals of this thesis. Chapter Two summarizes the literature review and current practices. Chapter Three describes the data collection and analysis procedure. Chapter Four estimates the cost for maintaining a paved road, and identifies the options for upgrading a road and the benefits from upgrading an unbound surface to a bound surface. Chapter Five presents the conclusions and recommendations from this research.

CHAPTER 2: LITERATURE REVIEW

Road Maintenance and Construction

According to the National Association of County Engineers, in order to maintain a successful road, there are ten key items to consider (1):

1) Keep water away from the road.
2) Build on a firm foundation.
3) Use the best soils available.
4) Compact soils well.
5) Design for winter maintenance.
6) Build for traffic loads and traffic volumes.
7) Pave only roads that are ready.
8) Build from the bottom up.
9) Protect your investment.
10) Keep good records.

According to Loren D. Evans of the United States Department of Agriculture (USDA) Forest Service, low volume roads should be constructed based on the function of the road, traffic volume, vehicle size, safety and environmental issues, and desired speed (2). In order for a low volume road to be designed at an economical cost, there needs to be flexibility in the use of the accepted guidelines and geometric design policies provided by the American Association of State Highway and Transportation Officials (AASHTO). New guidelines for the geometric design of very low-volume local roads have been developed by AASHTO and are less restrictive than previous design guidelines (3). According to

AASHTO, "a very low-volume local road is a road that is functionally classified as a local road and has a design average daily traffic volume of 400 vehicles per day or less" (3). In this AASHTO manual, several design examples and geometric standards are provided for various road functional and traffic classifications.

A low volume road design and construction manual has been prepared by the Minnesota Local Road Research Board and is titled "Best Practices for the Design and Construction of Low Volume Roads" (4). This report contains best practices information pertinent for designing and constructing low volume roads in Minnesota. Some of the information covered in the report is about designing hot mix asphalt (HMA) pavements with the mechanistic-empirical procedure (MnPAVE), as well as the evaluation of subgrade soils, specifications for embankment soil construction, and best practices for constructing low volume road projects so they follow specifications (4).

The Australian Road Research Board has developed a manual for maintaining and constructing sealed roads, "Sealed Local Roads Manual: Guidelines to Good Practice for the Construction, Maintenance, and Rehabilitation of Pavements" (5). The manual provides local governing authorities with a guide on current best practices for maintaining and constructing sealed roads in Australia and is divided into six main parts:

1) General – introduction to the manual, a description of surfacing options and materials, and discusses basic economic evaluation.
2) Design of New Pavements – covers initial design considerations, design procedures, and provides numerous examples.
3) Construction of New Pavements – covers all aspects of construction from site planning to paving equipment and quality assurance.

4) Maintenance Operation – discusses maintenance activities of road and roadside and includes information on assessments of pavements and treatments.
5) Pavement Rehabilitation – includes pavement evaluation techniques, identifying correct pavement treatments, and comparing cost and design of different overlays.
6) Miscellaneous – covers additional information on foot and bike paths, parking lots, airfields, and driveways.

Bituminous Treatments in Minnesota

The Minnesota Department of Transportation Office of Materials and Road Research has explored the use of thin bituminous treatments and other surfacing options for a road surface alternative. Greg Johnson, of the above-mentioned office, has performed field trials with the use of thin bituminous surface treatments, double chip seal, oil gravel, and Otta Seal, as possible surfacing options for roads that do not warrant receiving a full hot mix asphalt bituminous treatment. It is hoped with the use of the surfacing options, the maintenance costs for the roads will be reduced. Based on Johnson's field trials, these thin bituminous surface options have the potential for future road surfacing options. In addition, he has concluded that in order for these surface treatments to be successful in providing a surface that reduces maintenance costs, a strong base is needed (6). Costs for constructing these thin bituminous surfaces have been identified by Johnson, however, the costs for maintaining them are not currently known.

Blue Earth County has also paved an aggregate road with oil gravel or Finn road technology in hopes of providing a surface that is economical and easy to maintain compared to an aggregate road (7). Two test sections were constructed and according to Alan T.

Forsberg, the performance of each section had been good following one winter of use. The construction costs for these test sections were 33% less than a traditional 7-ton HMA pavement (7). Accurate maintenance costs had not been determined yet because the test sections were new and little maintenance had been performed at this writing.

Upgrading Aggregate Roads

Tight budgets, because of funding cuts passed down from national and state sources, population shifts, and poor economic conditions, make it challenging for counties to improve and or maintain the road network. A paper entitled "North Dakota Gravel Road Management Alternative Strategies" reports that decisions on how to maintain and or improve the existing road network need to be supported by collecting more data and maintaining better records that contain consistent data from year to year and county to county (8). Keeping better records and using a pavement management system will help in deciding which surfacing option to use and how to better maintain the existing road network. This report suggests that two important factors, traffic and cost data, must be recorded in a better way in order to help support the decision making process.

A computer application entitled Pavement Design and Management System (PDMS) can be used to optimize the pavement management strategies for low volume roads based on the total overall cost (9). The computer program optimizes the overall cost for pavement management by considering the cost for initial construction, maintenance, rehabilitation, user costs, and salvage over a twenty year period.

Robin Sukley of the Pennsylvania Department of Transportation, Bureau of Construction and Materials Engineering Technology and Information Division investigated cost effectiveness and performance of various treatment methods for upgrading existing aggregate roads (10). In this report bituminous seal coat options were compared. However, the costs are provided for the entire length of road, not just the treatment area. Thus, the costs could be misleading. The report does not determine which treatment is the most effective; it only compares the treatments against the performance of the control section.

According to a paper from the Kentucky Transportation Center, there are ten conditions that must be met before a road authority decides when to pave a gravel road (11):

1) After developing a road management program.
2) When the local agency is committed to excellence.
3) When traffic demands it.
4) After standards have been adopted.
5) After considering safety and design.
6) After the base and drainage are improved.
7) After determining the costs of road preparation.
8) After comparing pavement life and maintenance costs.
9) After comparing users costs.
10) After weighing public opinion.

There is some discussion of the general answers of when to pave a gravel road, however the road governing authority needs to come up with their own answers to continue the decision making process. In addition, the paper provides some suggested discussions that can be used by the road authority during the decision making process. If none of these answers are considered, then the governing agency may not be making an accurate and informed decision. This research project will identify key factors to be considered in deciding when to upgrade an aggregate road.

CHAPTER 3: DATA COLLECTION AND ANALYSIS

Justification for Selecting Data from Certain Counties

The initial data review process was initiated by visiting Waseca and Olmsted Counties to discuss this project and ascertain what types of information would be available. Waseca County provided a copy of the annual report that they submit to the Minnesota Department of Transportation State Aid Office (MNDOT SAO). This report included a detailed summary of the maintenances costs for each road, sorted by surface type. The report listed costs in four maintenance categories: Routine Maintenance, Repairs & Replacements, Betterments, and Special Work, and further broke down the costs associated with the Routine Maintenance category into costs for the activities listed under this category. The information in this report appeared to be very helpful for estimating the costs associated with maintaining roads with various surface types. Since all counties submit a similar report to the MNDOT SAO, the decision was made to collect copies of these reports from the afore mentioned office.

Background information on the annual reports is provided in the following. Each year counties are required to submit annual reports to the SAO to document how State Aid dollars were spent in the previous year for the County State Aid Road network. Upon review of the reports it was found the level of detail varied from one county to another. Generally the reports all documented spending for activities related to maintaining, improving, and constructing the county road system. Approximately 50 of the 87 counties in Minnesota provided reports for the time period from 1997 through 2001. Out of those 50 counties, 39 of them had costs broken down by road and 37 of those had costs also broken down by surface type. For 24 of those 37 counties, costs were broken down by Routine Maintenance, much like the Waseca County report, and 16 of those counties had costs broken down for all the maintenance categories in their annual reports. Since the annual reports for these 16 counties provided the most detailed information, it was decided to use them for the data analysis. Using the data from these counties creates a sample of convenience, which is necessary given the limited time for this research project and the need for sufficient amounts of historical data. It is hoped that this sample of convenience approaches the quality of a true random sample.

The 16 selected Minnesota counties were: Aitkin, Becker, Benton, Blue Earth, Chisago, Crow Wing, Kandiyohi, Lake, Martin, Mahnomen, Meeker, Norman, Rice, Waseca, and Winona. Saint Louis County was to be added after county personnel assisted in clarifying the data; however, this did not occur because of problems coordinating travel schedules. The addition of this county would have been desirable because it has a large road network. For future work in this research, it is recommended that Saint Louis County data be included for analysis. The selected counties are grouped into four general geographical regions. Because there are multiple sets of data from various regions of the state, the data is reasonably representative of that which could be collected from the entire state. It is expected that there will be differences of soil and climate types by region.

The four regions represented, shown in Figure 1, are as follows: Southern, Central, Northeastern, and Northwestern.

- The Southern region is represented by Martin, Blue Earth, Waseca, Rice, and Winona Counties.

- The Central region is represented by Kandiyohi, Meeker, Benton, and Chisago Counties.
- The Northeastern region is represented by Crow Wing, Aitkin, and Lake Counties.
- The Northwestern region is represented by Norman, Mahnomen, and Becker Counties.

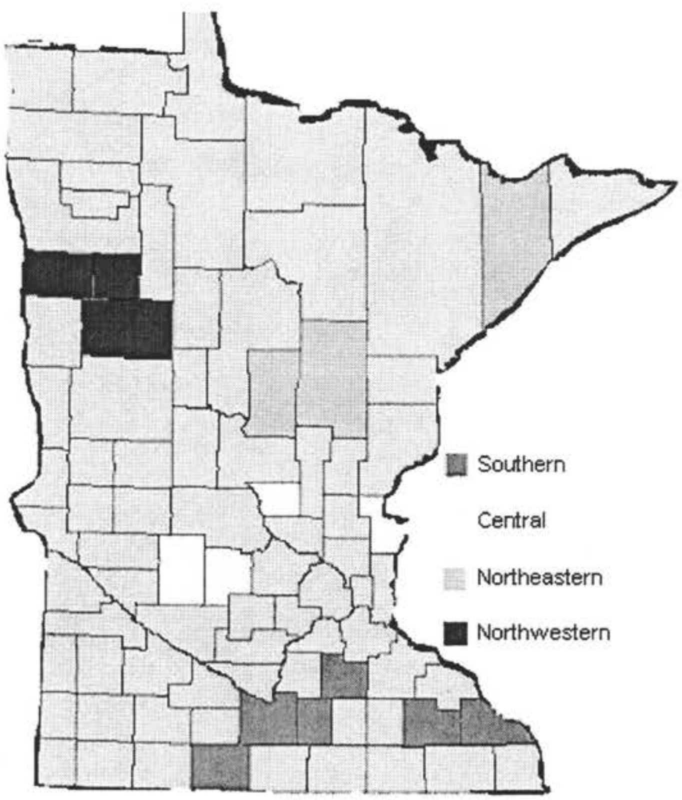


Figure 1. A map showing the counties selected in the different regions.

The southern region has a diverse topography from limestone bluffs in the east to rolling plains in the central to western side of the region. The soil type is highly suited for agricultural use. The central region has a slightly rolling terrain with predominantly sandy soils on the eastern side and loamy soils in the western half. Agriculture is more predominant in the western half. The northwestern region can be considered having two halves. The western half (Red River Valley) is an agricultural region with clayey soils, and a flat terrain. The eastern half is slightly rolling terrain around scattered lakes and woods with the soil being predominantly loam. The northeastern region is predominantly scattered lakes and forest region. The terrain ranges from gently rolling to hilly near Lake Superior. The loamy soil can be quite thin since bedrock is close to the surface. During certain times of the year, roads in these four regions are subjected to heavier loads than normal from farm equipment, grain trucks, manure wagons, and hauling timber. Tourist areas near lakes are also subject to larger traffic volumes, especially on summer weekends.

Cost data from each county was kept at the MNDOT SAO dating from 2001 back to 1997, which provided five years of data to analyze in determining representative maintenance and upgrading costs. Reports made from the 2002 data were not available in time for inclusion herein. Examining data from 1997 to 2001 allows for the use of the two most recent traffic maps, which are updated on a four-year cycle for the outlying counties, This makes it possible to find changes in traffic counts, possibly caused by population growth, that might affect changes in maintenance costs during that time period.

Description of Data and Maintenance Activities

Costs associated with roads are recorded in one of four main maintenance categories: Routine Maintenance, Repairs and Replacements, Betterments, and Special Work. Each of these are broken down further to include all the various activities necessary in maintaining a road. A description of each maintenance category and the activities associated with the category follow.

Routine Maintenance is broken down in to six subcategories that include: *smoothing surface*, *minor surface repair*, *cleaning culverts and ditches*, *brush and weed control*, *snow and ice removal*, and *traffic services* (including signs). These activities occur each year on a relatively regular basis and are performed to maintain and provide an adequate and safe driving surface for the public.

- The *Smoothing Surface* activity includes blading gravel roads and scarifying/mixing the gravel surface. This activity includes anything that would be specific to smoothing the road surface with material that is currently in-place (the addition of new material is a separate activity).
- *Minor Surface Repair* relates to all smoothing type activities occurring either on a bituminous or concrete road. Specific tasks include: patching and crack-sealing bituminous roads, repairing and crack-filling concrete roads, repairing frost boils and blow outs, cleaning/sweeping bridge decks and pavements, and shoulder repair with the existing material.
- The *Cleaning Culverts and Ditches* activity includes all items of work related to culverts and ditches already in place along the road. Particularly checking, cleaning, and thawing of culverts, checking and minor cleaning of ditches, repairing tile lines, lowering and raising culverts, and marking their ends. Also included in this category is the picking up of debris/trash, particularly road kill, from the roadway.
- *Brush and Weed Control* relates to all items concerned with maintaining the vegetation along the roadsides and in the ditches. Included are mowing and

spraying brush, grass, and weeds, spraying weeds and brush, and clearing and cutting of brush and trees along the roadway and within the clear zone.

- *Snow and Ice Removal* deals with clearing the roads of snow and ice. This includes cutting ice, plowing and winging snow from roads, sanding and salting roads, and clearing snow from bridges and guard rails.
- *Traffic Services* (including signs) deals with road signs and pavement markings. Specific items include maintaining posted and emergency 911 signs, striping the pavement, lighting of road intersections, and placing barricades as needed. Also included would be inspecting roads (examining their general condition), patrolling roads based on load restrictions, any emergency assistance that may be needed, and operation of a tourist station.

The Repairs and Replacements category can be further divided in to five subcategories that include: *reshaping*, *resurfacing*, *culverts, bridges, and guardrails*, *washouts*, and *storm cleanup*. Each one is then further divided into tasks that are of similar nature to the subcategory name. This category primarily involves activities associated with making repairs to the road and surrounding support structures that are more than minor in nature.

- *Reshaping* includes items related to the reshaping of the road surface and surrounding area. Particularly it entails minor reshaping of the roadbed, ditch, and backslope. It also includes reshaping the existing shoulders (no new material is used).

- *Resurfacing* deals with applying any new gravel material to a gravel road or shoulder and stabilizing the surface. Specific resurfacing activities include spot and continuous gravelling of the road surface, adding material to the shoulders (edge rutting), adding more binder to the road surface, and stabilizing a gravel surface.
- *Culverts, Bridges, and Guardrails* includes tasks related to those specific structures. Particularly it entails replacing an existing culvert (one that may have rusted through) with one of similar size, relaying culvert ends (so water will enter and exit pipe easier or flow through the pipe better), checking, repairing, and painting of the bridge, and assessing the counties ditches.
- The *Washouts* subcategory deals with repairing any washouts that might occur in the roadbed, shoulder, ditch, backslope, and culverts.
- *Storm Cleanup* includes the cleaning up and removal of debris on or along the roadway resulting from downed trees or other structures from thunderstorms. Also included would be the removal of mud and other items deposited on or around the roadway from prolonged and flash flooding.

The main category of Betterments can be further divided in to four subcategories which include: *new culverts, rails, or tiling*, *cuts and fills*, *seeding and sodding*, and *bituminous treatments*. Specifically this category relates to any new items that the county installs or major work undertaken by the county to better the road system.

- *New Culverts, Rails, or Tiling* involves the placement of new and larger culverts, any new guard rails and tile lines that might be installed along a road, the addition of any erosion control devices to the road area and the placement of rip rap along culvert ends, bridges, and edges of waterways to prevent or mitigate erosion. Also included in this category are the placement of new approaches or drives and the addition of aprons and extensions along the road surface.

- *Cuts and Fills* includes any major reshaping of the shoulders, roadbed, ditch, and backslope performed by the county and their own forces. This category also includes filling swamps and marshy areas.
- *Seeding and Sodding* deals with the establishment of new turf (seed or sod) and planting new trees and shrubs along the roadway to prevent erosion, provide wildlife habitat, or act as a natural snow fence.
- The subcategory *Bituminous Treatments* deals with treatments for bituminous road surfaces. Specifically it includes spot retreating of the road surface, applying an overlay, seal coating and sweeping a bituminous surface. This subcategory also involves maintenance money from any bituminous construction project and repairing railroad crossings.

Finally, Special Work is further divided in to three subcategories that include: *dust treatments*, *mud jacking and frost boils*, and *mailbox supports*. The main work counties perform under this category deals with dust control on gravel roads.

- The *Dust Treatments* subcategory includes the application of calcium or magnesium chloride and any other treatments that may be used to control dust on a road.

- *Mud Jacking and Frost Boils* includes mud jacking any pavement surfaces, repairing any frost boils and frost boil tile lines. Also included in this category are any repairs from flood damage and maintenance money from unallocated accounts.
- *Mailbox Supports* includes any work involving the repair and replacement of mailboxes being damaged during routine county maintenance operations, i.e. snow plowing, or removed by the county during the performance of "as needed" maintenance or construction, i.e. reshaping or new culverts.

The costs a county might incur while maintaining township or city roads are recorded under an additional maintenance category that is used by some counties, Special Agreements. This category includes any agreements with individual cities or townships within the county for maintaining their roads in the summer or plowing snow in the winter or administering construction projects on city or township roads.

While the above mentioned maintenance activities are necessary in maintaining a safe roadway area for the traveling public, the performance of some activities depends on the type of road surface. Some maintenance activities primarily related to gravel roads include *smoothing surface*, *dust treatment*, and *resurfacing*. Activities such as *minor surface repair* and *bituminous treatments* primarily occur on paved roads, either bituminous or concrete. *Snow and ice removal* and *traffic services* are two activities that occur on all types of roads, however, the amount of work done for each activity is greater on paved roads than gravel roads. Other activities are necessary in maintaining the overall integrity of the road and area surrounding the road, such as *brush and weed control, cleaning of culverts and ditches, seeding and sodding*, and *washouts.*

Maintenance activities occur at different times of the year, some activities occur on a regular basis because they are routine in nature, while others occur on an "as needed" basis. Deciding whether a maintenance activity is routine or "as needed" depends somewhat on individual opinion. Some activities occur every three or four years and may be classified as a routine activity by one individual because the time interval between occurrences is predictable. However, because an activity does not occur year after year, another individual may classify that particular activity as an "as needed" activity because they do not need to budget for the activity each year. This paper will classify the activities in the Routine Maintenance category as routine maintenance activities because they occur throughout the year on a regular basis for most, if not all, the roads in a county's road system. *Dust treatments* is an example of a borderline routine maintenance activity. Even though it occurs year after year (typically twice per year) it does not always occur in the same location or the same number of times per year. Since *dust treatments* do not usually occur on a paved road and does not occur on a regular basis, this maintenance activity will be considered as an "as needed" maintenance activity. In addition, the remaining activities listed in the Repairs & Replacements, Betterments, and Special Work categories will be considered as "as needed" maintenance activities. Even though there is an expectation for when the *resurfacing* and *bituminous treatments* activities will occur, these activities do not always occur on a regular interval. Therefore, they will be considered to occur on an "as needed" basis. For the purpose of data analysis, all of the activities considered to occur on an "as needed" basis, except for the *bituminous treatments* activity, were combined into one activity, called *others*, and used in the data analysis. This action was taken because the cost per mile for each of these activities contributes a small portion to the total cost per mile for maintaining a road, in comparison to the contribution of the Routine Maintenance activities.

Statistical Analysis

To analyze the data, a statistical analysis of the data would be helpful in determining the data trends, means, and for predicting or modeling future costs. To analyze the data, it was decided to first perform regression analysis and then principal component analysis. By performing a statistical analysis of the road maintenance cost data from the selected sixteen counties in Minnesota, it was hoped that the following results would be possible:

1) Identification of which maintenance activities have an important role in influencing the maintenance cost for each road surface type – gravel, bituminous, and concrete. By knowing which activities play a key role in influencing the maintenance costs for a road of a given surface type, more effort can be put to tracking those costs and finding ways to improve those particular maintenance activities. Also, since some counties only have records keeping track of the total cost for each maintenance category for each road, it will be useful to identifying the proportion of the total cost that the key maintenance activities play in influencing the total maintenance cost. These percentages can then be used to back out similar costs from the total cost for each maintenance category of which the counties keep track.
2) Identification of which maintenance activities are affected by the traffic volume for the road. The cost of some road maintenance activities may be directly related

to the volume of traffic traveling over the roadway. By knowing which activities are affected by traffic volumes, then it will be easier to predict how money needs to be budgeted for future maintenance activities based on the predicted growth of the traffic volumes.

3) Estimation of average maintenance costs for the road surface based on various traffic volumes and the various regions of the state – i.e. groups of counties. These average maintenance costs can then be used as predictors for determining maintenance costs for surrounding similar counties. They also can be used to predict future costs the county will have for maintaining a given road surface as traffic volumes change.

4) Selection of certain activities that can be used to predict the maintenance costs for maintaining a road – i.e. if *x* activity increases in cost by a given amount *a*, then the total maintenance costs for the road will increase by an amount *b*.

5) Identification of regions in the state where combinations of various maintenance activities will predict the total maintenance costs for the roads in the particular region. The identification of the maintenance activity costs that play a key role in the total maintenance costs for a road in certain regions throughout the state will be helpful in refining the ability to predict future maintenance costs and identify other factors in the region that might affect costs, such as soil and vehicle traffic types.

Initial Statistical Analysis

Initial statistical analysis of the road maintenance cost data from the selected sixteen counties in Minnesota was performed with the data from Waseca County. Using this data, a regression analysis was performed to identify which, if any, of the maintenance activities played a statistically significant role in estimating the total cost of maintaining the road. After performing the statistical analysis, it was found that the total cost of maintaining a road was dependent upon all of the maintenance activities. Upon further analysis it was found that all the maintenance activities would be approximately equally significant in determining the final total cost, since the total cost for maintaining a road depends on the cost of each individual maintenance activity. This finding is intuitively obvious and does not add to the knowledge of the data and estimation of costs to maintain a paved road.

Next the data was analyzed by performing a principal component analysis using SAS 8.2 software (12). This allows data that has multiple categories or variables to be summarized in two or three components, which improves the ability to visualize data. These summarized components are combinations of the original variables that provide a method of identifying possible correlations between the data. This process calculates the eigenvalues of the correlation matrix of all the variables which can then be used to identify the components that account for the greatest amount of total variance in the original variables. These first few components that account for most of the variance in the data can then be used to summarize the data set and possibly used for further statistical analysis.

The principal component analysis for the Waseca County data indicated that *minor surface repair*, *traffic services*, and *snow & ice removal* accounted for the most variance in the data for bituminous surface roads. Those three activities identified by the principal component analysis were also thought, based on previous knowledge, understanding, and experience of bituminous county road maintenance activities, to be important in determining the total cost to maintain a bituminous road. When examining the data on a cost per mile basis, the activities that contributed the most to the total Routine Maintenance category cost per mile are the ones that the principal component analysis determined. So, it was decided that estimating the average costs per mile over a five year time and then identifying which activities had the largest cost would be sufficient in selecting which activities are most important to track in order to estimate the cost of maintaining a paved road. The results from the principal component analysis are shown in Appendix A.

Another Statistical Analysis

For possible further statistical analysis of the data and possible prediction of future costs, a regression variable selection method was used in attempt to identify which combinations of variables for each maintenance category would give the largest R-squared value. The closer the R-squared value is to one for each model of possible combinations of variables, the better the model will be for predicting the actual cost of the specific maintenance category for each road. This analysis was performed to identify the four best 2, 3, and 4 variable models. The more variables that are added to the model, the larger the R-squared value and thus the better the model will be at predicting the total cost for each maintenance category. The objective of this analysis was to identify the fewest number of variables that could be used to predict the total cost. This is desired to minimize the amount of data to be collected and to allow for better collection of the data that needs to be collected.

Initial analysis of data by this method was performed for all of the routine maintenance data for Aitkin, Benton, and Meeker Counties. Examination of the results showed that all three counties had different combinations of variables that resulted in the largest R-squared value. In fact the counties had different combinations of variables for the different years of data for each county. This difference amongst and within counties resulted in eleven different 3 variable models and seven different 2 variable models. However, even though several models had the same combinations of variables, the R-squared values differed for each model. The difference in R-squared values is to be expected since we are dealing with several different years of data, but these models in the current form are only useful for predicting costs for other similar roads of that type during the given year from which the models were determined. Thus, they cannot be generalized and the usefulness to predict future costs is minimal.

Since the models varied for routine maintenance and did not provide any definite information, it seemed unlikely that an effort in developing models for other maintenance categories or other counties would yield usable results. Therefore, no other analysis was performed; however, maybe with more anecdotal information, changes could be made in the models to improve their usefulness. It should also be noted, the models only work for predicting future costs by assuming the costs associated with maintaining a paved road are not changing over time; which is unlikely to be a good assumption. The role of nature, causing excess rains and flooding or producing a cold and snowy winter, alone creates variation in the amount of maintenance required for any given road. Shrinking maintenance budgets also reduce the amount of funding available for activities to be performed. So, the regression variable selection analysis would likely provide little new information in predicting future costs and therefore was not performed on other data.

New Analysis Process

Since the previously mentioned statistical analyses did not add new knowledge, other than it did not work, or produce results that were not already intuitively obvious, it was decided to discontinue these processes. It is believed that the data set being used has not necessarily been collected with the same detail and consistency from one county to the next, so performing one of the previously mentioned statistical analyses might not provide reliable results and analysis. Instead, the data was analyzed using descriptive statistical analysis. This includes calculating the mean (average) cost per mile over the five year time span of the data, the standard deviation of the data, then calculating a 95% confidence interval for the mean of each activity, and finally computing the five number summary for each activity. After calculating these values, the data was then analyzed to determine which activities had the greatest proportion of the total cost for each maintenance category and for all the maintenance categories combined. Also, this analysis serves as a model for road maintenance authorities who wish to perform a similar analysis with a spreadsheet program. To do the analysis a program needs to have the capabilities to sort data, and calculate means, standard deviations, and confidence intervals; and then be able to graph results. Microsoft Excel (version 97 or newer) has this capability, and is what was used for the analysis of the data in this research. A box plot, showing the distribution of the data, is shown in Appendix A.

The data set from all sixteen counties for five years for all paved roads would be extremely large; it would not be within the scope of the study to interview county personnel and analyze data for 16 counties. Thus it was decided to conduct interviews with the county officials and perform the previously described descriptive statistical analysis on the reduced data set of five counties: Aitkin, Benton, Blue Earth, Kandiyohi, and Meeker. These counties were selected because their location still allowed for a representation of data from various regions throughout the state of Minnesota. The location of these counties is shown in Figure 2. Olmsted and Waseca Counties, which were interviewed during the initial phases of this study, are shown in Figure 2 because the information gained from the interviews is also included in this study.

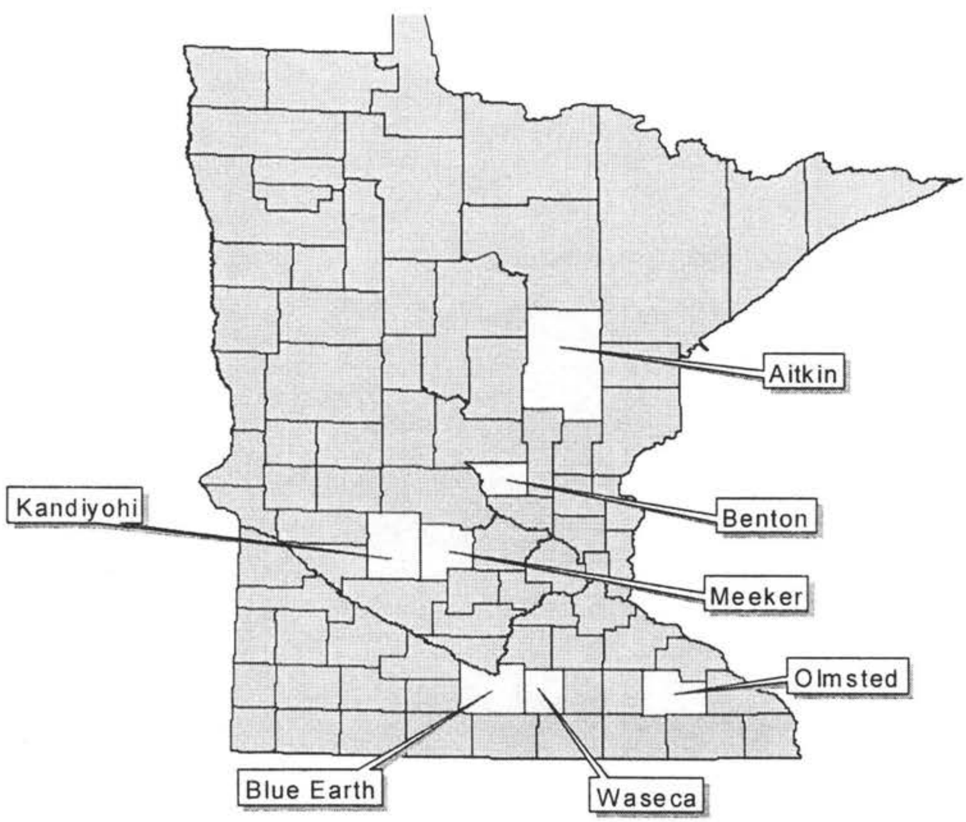


Figure 2. A map (13) of Minnesota showing the counties interviewed and used in the data analysis.

CHAPTER 4: COSTS AND BENEFITS

Results from analyzing the data and information gained from interviews with county engineers follow in the next sections of this chapter. The first part of this chapter involves the analysis of the county costs. Then surfacing options for upgrading or "paving" a gravel road are discussed along with decision factors on which road to pave and when to pave a road. Finally, the benefits of having a paved road are discussed.

County Write Ups

The bituminous roads used in the data analysis had varying lengths, so the total costs reported for each road were converted to a cost per mile basis to compare and analyze the road cost data in the same manner. Even though costs for analysis are on the same scale, it still needs to be realized that roads of shorter lengths may have higher costs because the initial startup and operational costs are spread over a shorter distance. As the data was analyzed, it was also grouped in nine traffic volume ranges. These traffic volume ranges were decided upon based on conversations with county personnel on breakdowns in the level of service provided for bituminous and gravel roads.

Aitkin County

Aitkin County is located in the north-central part of Minnesota, in an area considered by many as the lakes region, and is an area of 1819 square miles composed of 55 Townships. The county has about 511 miles of road, 374 are County State Aid Highway (CSAH) roads with about 197 miles paved and the remaining 177 miles are gravel. Of the 137 miles of County roads, 17 miles are paved and 120 miles are gravel. Approximately two-thirds of the land in the county is publicly owned, most of that land being acquired from original landowners who defaulted on loan payments when they originally bought the land and tried to drain it for agricultural purposes. However, now the county is growing slowly into a year round retirement community. Currently the year round population consists of about 15,000 residents, while during the summer the population can swell up towards as many as 60-80,000 people on any given weekend.

The reason for this large population increase in the summer is because people are attracted to the numerous lakes within Aitkin County and the numerous cabins and lodges on the lakes. During the summer, people drive approximately two hours to their cabins from the Twin Cities metropolitan area to spend time at their cabin or on the lake for the weekend. This population fluctuation results in a travel pattern that causes the traffic counts on a road to fluctuate considerably from one day to the next. During the summer months, a road may have an average daily traffic (ADT) of 100 during the week, but on the weekend, the ADT may increase to 500. During the winter, the same road may have an ADT of only 20 for the entire week. As the traffic volume changes throughout the year, so does the amount of maintenance required and performed. Because of these changing traffic volumes, ideally, it would be good to have a road surface that is relatively easy and cost effective to maintain during the summer and winter months, such as a paved surface.

In Aitkin County the average cost/mile to maintain all paved roads from 1997 to 2001 was $2952 ± 523, which includes all the categories and activities listed in Table 1. Table 2 shows the average cost/mile to maintain a paved road for each of the four maintenance categories and by various traffic volume groupings. In addition to showing the costs per mile to maintain a bituminous road, Table 2 also lists the number of road segments and total miles of road for each traffic volume grouping. For all the paved roads maintained in Aitkin

County, 71% of the cost is attributed to the activities found in the Routine Maintenance category, with the average cost per mile being $2111 ± 173 for a 95% confidence interval. A break down of those costs associated with the Routine Maintenance category are shown in Table 3.

Table 1. Listing of cost categories and activities found in the county cost reports.

Routine Maintenance	Repairs & Replacements	Betterments	Special Work
Smoothing Surface	Reshaping	New Culverts, Rails or Tiling	Dust Treatments
Minor Surface Repair	Resurfacing	Cuts & Fills	Mud Jacking & Frost Boils
Cleaning Culverts & Ditches	Culverts, Bridges, Guardrails	Seeding & Sodding	Mailbox Supports
Brush & Weed Control	Washouts	Bituminous Treatments	
Snow & Ice Removal	Storm Cleanup		
Traffic Services			

Summaries of the costs per mile, including the means, standard deviations, and 95% confidence intervals, for all the maintenance activities performed to maintain a paved road in the analyzed counties can be found in Appendix B. Appendix C is a CD-ROM that contains five number summaries of the data and the original entered data sets used for analysis.

Table 2. Average maintenance costs per mile for paved roads in Aitkin County.

Traffic Volume	Routine Maintenance	Repairs & Replacements	Betterments	Special Work	Total Cost/Mile	# of Road Segments	Miles of Road
all	$2111	$360	$464	$17	$2952	179	944
0-49	$1635	$0	$0	$0	$1635	2	1
50-74	$2119	$14	$7	$0	$2139	10	11
75-99	$1957	$221	$58	$0	$2235	8	19
100-124	$2684	$219	$119	$9	$3032	9	26
125-149	$1960	$119	$42	$0	$2122	10	54
150-199	$1552	$391	$16	$9	$1968	12	81
200-249	$1833	$973	$903	$0	$3708	8	77
250-299	$1913	$318	$272	$43	$2545	32	210
300-up	$1893	$328	$558	$0	$2779	61	447

The other three maintenance categories, Repairs & Replacements, Betterments and Special Work, all contain activities that do not necessarily occur each year. Some of these activities that do not occur on a yearly basis for each road that contributed to increasing the overall maintenance cost/mile include repairs from *washouts*, *cuts & fills*, and *bituminous treatments*. These three activities are the primary source for the additional costs in maintaining the paved roads. The cost per mile for the *bituminous treatments* and *resurfacing* activities found in the Betterments and Repairs & Replacements categories, respectively, could be subtracted from the overall cost per mile to maintain a paved road. Because these activities typically occur every five to six years instead of on a yearly basis, they can be considered as individual construction or maintenance activities necessary in maintaining the service life of the paved road but not necessary for day to day operations of the road.

Table 3. Average costs per mile for Routine Maintenance activities on paved roads in Aitkin County.

Traffic Volume	Smoothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Sub-Total Cost/Mile
all	$43	$226	$87	$178	$1048	$530	$2111
0-49	$0	$79	$0	$94	$1116	$348	$1635
50-74	$0	$283	$0	$150	$1218	$469	$2119
75-99	$0	$113	$94	$163	$1076	$510	$1957
100-124	$209	$579	$5	$104	$1250	$538	$2684
125-149	$0	$358	$22	$175	$876	$529	$1960
150-199	$154	$59	$22	$147	$703	$467	$1552
200-249	$18	$46	$140	$269	$888	$472	$1833
250-299	$54	$94	$66	$176	$1024	$499	$1913
300-up	$5	$165	$48	$224	$881	$571	$1893

Figure 3 provides a graphical representation of the costs per mile for maintaining a paved road for several traffic volume ranges. In all the traffic ranges, the activities found in the Routine Maintenance category make up the majority of the costs for maintaining a paved road. Only for the traffic range of 200-249 ADT do the *others* and *bituminous treatments* activities contribute significantly to the cost per mile in maintaining a paved road. Figure 2 suggests that the cost to maintain a paved road on a per mile basis may not increase with increasing traffic levels.

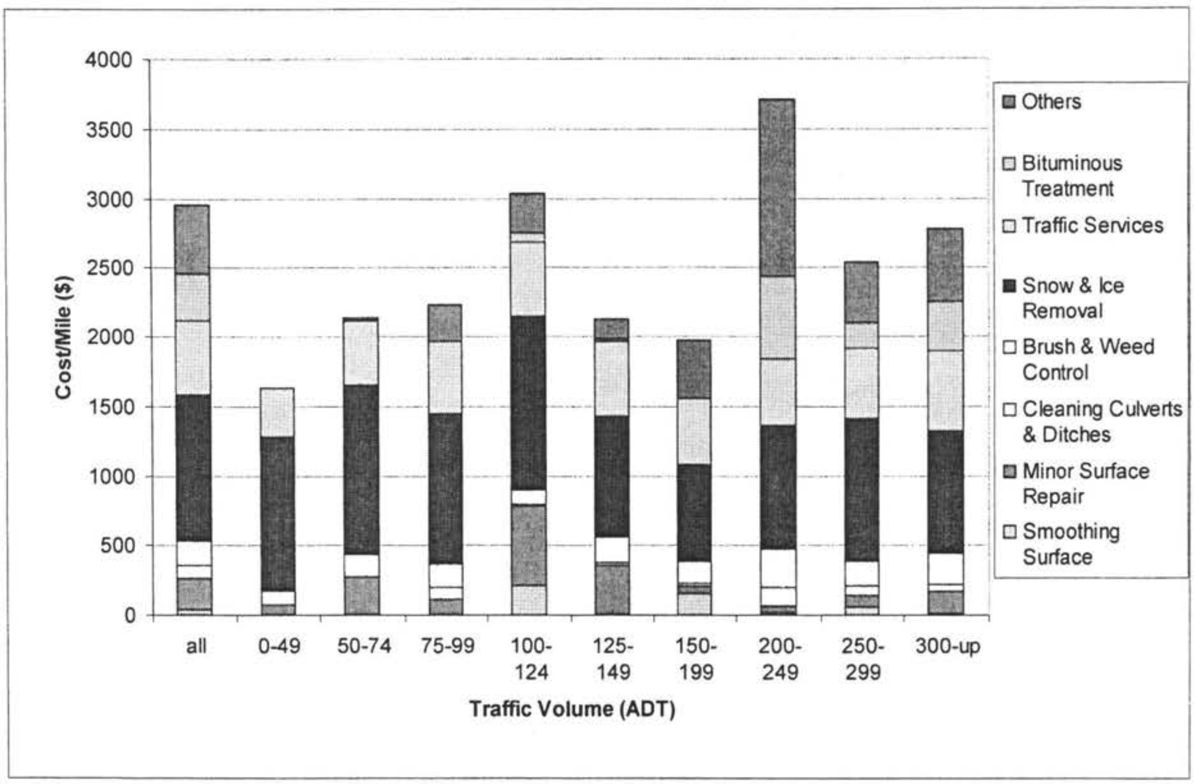


Figure 3. The average costs per mile for all the activities performed to maintain the paved roads of different traffic volume ranges in Aitkin County.

Benton County

Benton County is located in the central portion of Minnesota, east of Saint Cloud, and has an area size of 408 square miles containing 12 Townships. The county has 453 miles of road, which is split rather equally between CSAH and County Roads. Approximately 220 miles of the roads in the county are CSAH Roads, of which about 215 miles are paved. Of the remaining approximately 235 miles of County Roads, around 115 miles of those are paved. The county has a population of a little more than 34,200 people and is experiencing slow steady growth, especially in the western portion of the county, near the Saint Cloud metropolitan area.

The average cost per mile to maintain a paved road in Benton County from 1997 to 2001 was $3656 ± 660, with about 41 and 44% of the costs coming from the Routine Maintenance and Betterments Categories, respectively. The average cost per mile for a paved road falling into one of the nine different traffic ranges in Benton County is shown in Table 4. This table also includes the number of road segments and total miles of road for each traffic volume range. During this time frame, many portions of the roads in Benton County were treated with a bituminous treatment, seal coat or overlay, in order to extend their service life. In addition, many of the roads that received *bituminous treatments* also experienced some *reshaping*; this explains most of the average cost of about $500 per mile for Repairs & Replacements. Depending on when the *bituminous treatments* are performed, this investment will typically not be required on many of the roads for about another five years. Since it will be awhile before the *bituminous treatments* occur again, the costs in maintaining the roads during this time will be much less, roughly $1600 less per mile.

Table 4. Average maintenance costs per mile for paved roads in Benton County.

Traffic Volume	Routine Maintenance	Repairs & Replacements	Betterments	Special Work	Total Cost/Mile	# of Road Segments	Miles of Road
all	$1487	$501	$1632	$35	$3656	289	1597
0-49	$2389	$7	$321	$0	$2716	15	5
50-74	$1185	$619	$2210	$0	$4013	10	15
75-99	$1361	$643	$2697	$62	$4763	20	53
100-124	$1133	$1045	$4278	$8	$6464	10	24
125-149	$1290	$776	$2944	$32	$5043	20	90
150-199	$1594	$680	$3767	$10	$6052	15	56
200-249	$1220	$332	$999	$11	$2562	50	385
250-299	$1334	$614	$2619	$9	$4577	20	85
300-up	$1661	$433	$816	$68	$2977	110	884

When only looking at the costs for maintenance activities that occur on a yearly basis for a paved road, those in the Routine Maintenance category, the average cost on a per mile basis to maintain a paved road in Benton County drops to $1487 ± 97, or about $125 per mile per month. Table 5 provides a break down of the costs per mile for the activities performed to maintain a paved road, which are associated with the Routine Maintenance category. The majority of the costs associated with this category fall under the activities of *snow & ice removal*, *traffic services*, *minor surface repair*, and *brush & weed control*, with the costs occurring on a relatively even basis throughout the year.

Table 5. Average costs per mile for Routine Maintenance activities on a paved road in Benton County.

Traffic Volume	Smoothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Sub-Total Cost/Mile
all	$52	$246	$43	$169	$572	$406	$1487
0-49	$38	$415	$44	$89	$1183	$621	$2389
50-74	$49	$131	$13	$424	$298	$271	$1185
75-99	$173	$146	$61	$135	$523	$322	$1361
100-124	$13	$108	$6	$152	$503	$352	$1133
125-149	$57	$289	$10	$165	$430	$338	$1290
150-199	$15	$217	$22	$148	$624	$568	$1594
200-249	$17	$211	$42	$163	$499	$289	$1220
250-299	$11	$299	$40	$170	$478	$336	$1334
300-up	$17	$302	$62	$184	$641	$455	$1661

A graphical representation, separated by traffic volumes, of the costs associated with all maintenance activities, including those occurring on a regular or irregular basis is shown in Figure 4. The costs associated with maintaining a paved road do not seem to depend on the amount of traffic present on a road. However, it does appear that these costs do increase from the 50-74 ADT range on up. Again, it is obvious that the activity contributing the most is from the *bituminous treatments* category.

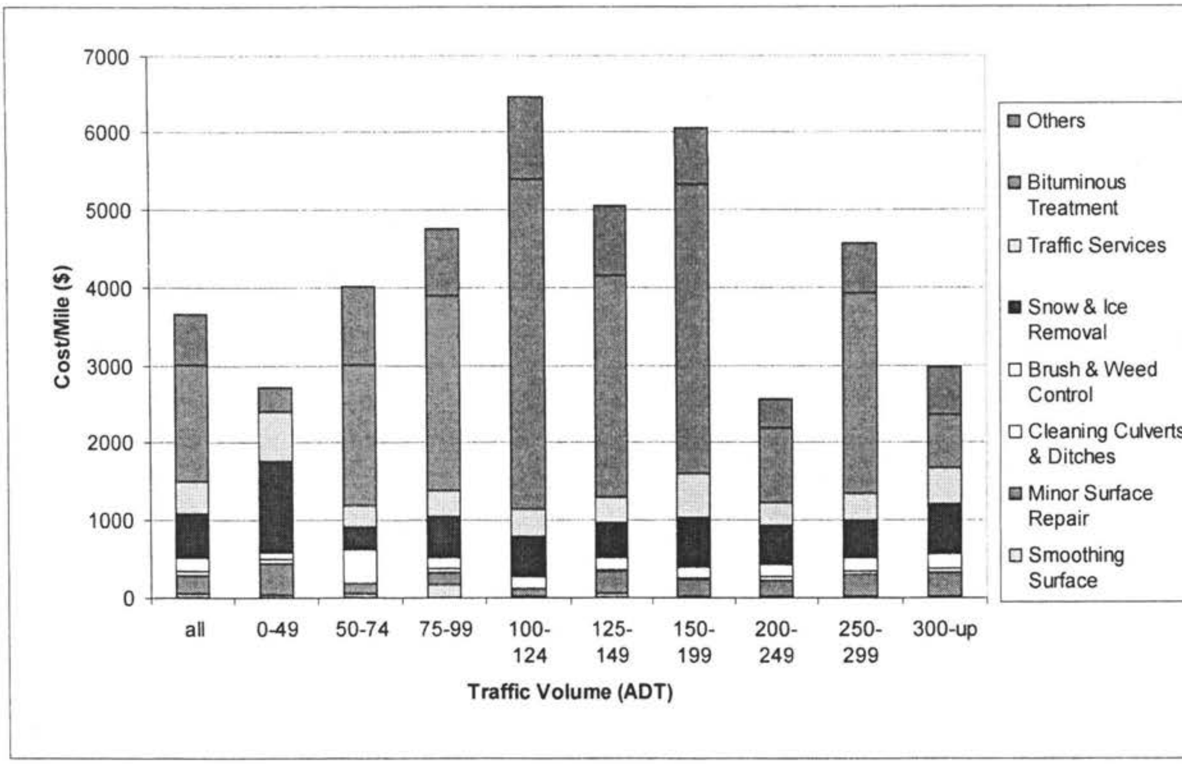


Figure 4. The average costs per mile for all the activities performed to maintain the paved roads of different traffic volumes in Benton County.

Blue Earth County

Blue Earth County is located in south-central Minnesota, with Mankato being a large population center. The county has an area size of 764 square miles and contains 23 Townships. There are approximately 720 miles of road in the county, with about 400 miles being CSAH roads and the remaining 320 County Roads. Of the 400 miles of CSAH roads, about 380 miles are paved and the remaining are gravel. Approximately 40 miles of the 320 miles of County Roads are paved, leaving 280 miles of gravel County Roads. The county is growing, mostly in the area in the vicinity of Mankato, and has a population of about 56,000 people. The city of Mankato serves as a regional hub for business, entertainment, and manufacturing for the surrounding counties and smaller cities, serving an estimated population of 222,000 people.

Table 6 lists the average cost per mile for paved roads in Blue Earth County and includes the number of road segments and total miles of road for each traffic volume range. The average cost for all paved roads is \$4356 ± 566, with about 55% and 26% of the costs coming from the Routine Maintenance and Betterments categories, respectively. The costs for Betterments and Repairs & Replacements make up about half the costs to maintain a paved road, because Blue Earth County has been actively *resurfacing* and applying *bituminous treatments* to their roads in order to extend their service life. However, these costs do not occur every year on the same stretch of road. There are two possible ways of tracking these costs: First, the costs can be spread out over the lifetime of the road; which is done when estimating the average cost to maintain a road. Second, the costs can be considered as one construction or maintenance activity that is performed approximately every six years; so it is added to the cost of maintaining the road at that point in time. In the latter case, then the average annual cost to maintain a one mile stretch of a paved road in Blue Earth County is essentially the cost found in the Routine Maintenance category, \$2405 ± 255. The costs for the activities associated with the Routine Maintenance category are further broken down in Table 7.

A review of the costs associated with the Routine Maintenance category, indicates that approximately two-thirds of the costs are associated with *minor surface repair* and *snow & ice removal*. The first activity performed primarily in the summer and the latter performed during the winter months. The costs related to the remaining one-third of the costs for Routine Maintenance come primarily from *traffic services* and *brush & weed control*. Some of the traffic volume ranges have costs for the *smoothing surface* activity that are much higher in comparison to the other traffic ranges. This most likely is a result of how the work or repair activity was classified on the time card of those who performed the work, since *smoothing surface* and *minor surface repair* have activity titles that may seem similar to some workers. The first is intended for activities to smooth a gravel road and the latter is intended for smoothing a bituminous road. It is easy to understand how an activity may be recorded under the wrong cost code. This is especially true if the work being performed was for perhaps the repair of potholes, depressions, or areas in the paved surface that may have corrugated causing a rough ride. In this case the work being performed would seem to fall under the *smoothing surface* activity (that applies to aggregate roads) because the work performed is smoothing the road surface. However, because this work being performed is smoothing the surface of a paved road, the work should be recorded under the cost code of *minor surface repair* (that applies to paved surfaces).

Table 6. Average maintenance costs per mile for paved roads in Blue Earth County.

Traffic Volume	Routine Maintenance	Repairs & Replacements	Betterments	Special Work	Total Cost/Mile	# of Road Segments	Miles of Road
all	$2405	$831	$1117	$2	$4356	419	2058
0-49	$1774	$757	$222	$0	$2753	9	9
50-74	$1272	$819	$127	$1	$2219	8	8
75-99	$1929	$875	$760	$4	$3568	17	58
100-124	$1576	$493	$400	$0	$2469	14	60
125-149	$1656	$539	$1223	$4	$3422	29	60
150-199	$1903	$445	$1132	$1	$3481	48	209
200-249	$1917	$629	$537	$8	$3090	19	64
250-299	$1691	$502	$1063	$2	$3258	29	172
300-up	$2338	$994	$1117	$3	$4452	187	1346

Figure 5 provides a graphical representation, by traffic volume range, of the costs per mile for the activities performed to maintain the paved roads in Blue Earth County. The graph shows a slight trend to an increase in total costs per mile for maintaining a paved road as the traffic volume on the road increases. This seems to be truer for activities in the

Routine Maintenance category. An obvious increase in cost per mile occurs from the 50-74 ADT range to the 75-99 ADT range. The main difference in cost between these two traffic ranges is the result of very little *bituminous treatments* occurring in the 50-74 ADT range. With more *bituminous treatments* being performed, then there is an increase in cost for *traffic services* because the road needs to be striped again, which is another difference in cost between these traffic ranges. Finally, the roads in the 50-74 ADT range may be older which would explain the increase in cost per mile for *minor surface repair* and *bituminous treatments*. Closer examination of Figure 4 and Table 6 indicates there is an overall increase of approximately $600 per mile from the 0-49 ADT range to the 300-up ADT range for all Routine Maintenance activities.

Table 7. Average costs per mile for Routine Maintenance activities on a paved road in Blue Earth County.

Traffic Volume	Smoothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Sub-Total Cost/Mile
all	$135	$728	$71	$325	$843	$303	$2405
0-49	$372	$457	$64	$260	$491	$130	$1774
50-74	$353	$14	$32	$185	$621	$67	$1272
75-99	$267	$491	$89	$245	$694	$144	$1929
100-124	$122	$485	$24	$217	$580	$148	$1576
125-149	$320	$247	$18	$243	$714	$114	$1656
150-199	$139	$549	$39	$300	$684	$192	$1903
200-249	$346	$556	$14	$237	$571	$192	$1917
250-299	$193	$419	$43	$250	$583	$204	$1691
300-up	$71	$832	$74	$295	$721	$345	$2338

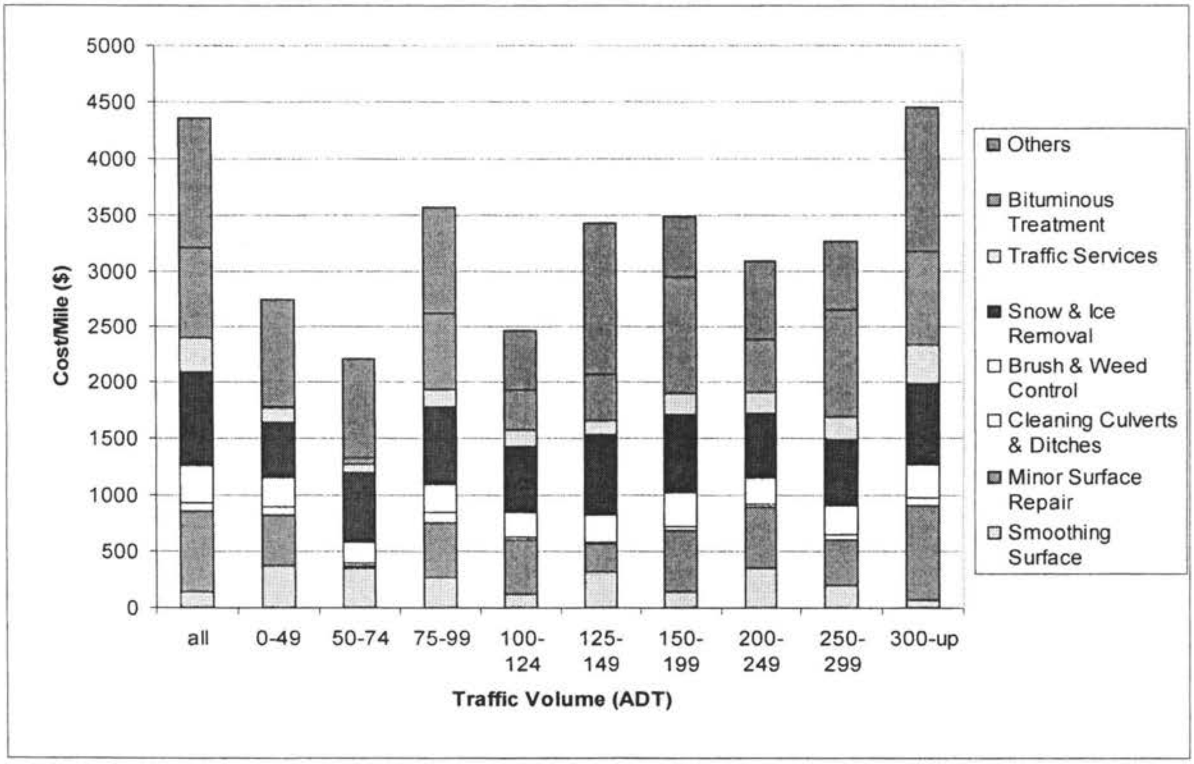


Figure 5. The average costs per mile for all the activities performed to maintain the paved roads of different traffic volumes in Blue Earth County.

Kandiyohi County

Kandiyohi County is located in the west central portion of Minnesota, with Willmar being the county seat; it has a size area of 864 square miles consisting of 24 Townships. The county maintains 645 miles of roads, of which 65% are CSAH Roads and 35% are County Roads. There are approximately 428 miles of paved roads, with a vast majority of them being CSAH Roads. Approximately 385 miles of the CSAH Roads in Kandiyohi County are paved with the remaining miles being surfaced with gravel. Almost 35 miles of the County Roads are paved in Kandiyohi County and the rest of the County Roads have a gravel surfacing. The county is growing slowly and has a population of a little more than 41,000 people.

The average cost to maintain a mile stretch of paved road in Kandiyohi County is $1917 ± 179. Table 8 lists the average cost per mile to maintain a paved road for all traffic volumes and provides costs for various traffic volume ranges. Also listed in Table 8 is the total number of road segments and miles of road for each traffic volume range. Approximately 75% of the total costs in maintaining a paved road in Kandiyohi County come from the activities involved in the Routine Maintenance category. The remaining 25% of the costs to maintain a paved road come from primarily the activities of *resurfacing* and *bituminous treatments*, found in the categories Repairs & Replacements and Betterments. These two activities do not typically occur on a yearly basis for the same mile of road and are activities performed to improve the overall serviceability and life of the existing pavement. The costs for these activities could then be considered as a lump cost when they actually occur as construction activity instead of spreading the cost out over multiple years. Subtracting these cost from the total average cost to maintain a mile stretch of paved road in Kandiyohi County results in the remaining cost per mile to be $1445 ± 123.

Table 8. Average maintenance costs per mile for paved roads in Kandiyohi County.

Traffic Volume	Routine Maintenance	Repairs & Replacements	Betterments	Special Work	Total Cost/Mile	# of Road Segments	Miles of Road
all	$1445	$245	$225	$1	$1917	306	2034
0-49	$1137	$409	$22	$0	$1569	10	3
50-74	$1406	$1835	$0	$0	$3241	3	3
75-99	$2998	$73	$0	$0	$3070	5	2
100-124	$1255	$556	$19	$0	$1830	15	39
150-199	$1872	$418	$182	$1	$2472	35	76
200-249	$946	$420	$225	$0	$1592	20	74
250-299	$1018	$62	$666	$0	$1746	10	78
300-up	$1493	$183	$294	$1	$1971	173	1759

Table 9 provides a break down of the costs per mile for the activities associated with the Routine Maintenance category. Nearly two-thirds of the costs associated with Routine

Maintenance activities come from *snow & ice removal* and *traffic services*, with most of the remaining one-third of the costs being spread out equally amongst the other activities when looking at all roads together. Five of the traffic volume ranges have much higher costs for *smoothing surface* compared to the remaining traffic volume ranges; however, most of those same five traffic volume ranges also have smaller costs for *minor surface repair*. A possible reason for the disparity in these values comes from how the particular maintenance activity for the roads in those traffic ranges was recorded on the time sheet. For example, one activity a person may consider as a *smoothing surface* operation, while it may be considered by many others as a *minor surface repair* activity. This leads to the possibility of there being some ambiguity in recording the work performed under the correct cost activity description.

Table 9. Average costs per mile for Routine Maintenance activities on a paved road in Kandiyohi County.

Traffic Volume	Smoothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Sub-Total Cost/Mile
all	$121	$166	$118	$122	$684	$234	1445
0-49	$341	$8	$6	$178	$506	$99	1137
50-74	$683	$17	$86	$110	$370	$140	1406
75-99	$57	$166	$116	$239	$2135	$285	2998
100-124	$308	$240	$17	$75	$460	$154	1255
150-199	$278	$354	$54	$197	$766	$224	1872
200-249	$274	$45	$42	$67	$356	$162	946
250-299	$2	$118	$43	$94	$491	$271	1018
300-up	$58	$153	$144	$126	$728	$283	1493

Figure 6 provides a graphical representation of the costs, on a per mile basis, associated with maintaining the paved roads in Kandiyohi County. The costs are grouped by traffic ranges and do show a slight trend of increasing costs with increasing traffic volume. In fact, the graph raises a question as to why the *snow & ice removal* costs are so high for the 75-99 ADT traffic volume range. After reviewing the data, it seems to be that the average lengths of the roads in that traffic range are less than a mile. As a result, when costs are assigned for removing ice and snow from these roads, it appears that a greater portion of the costs for this activity are assigned to these roads. When performing *snow & ice removal* activities, there is probably an initial expense, much like a mobilization expense, in having the equipment and operator to perform the work and then getting them out to the work area. On longer stretches of road this cost is spread out over many miles of road so it is less noticeable; however, for shorter stretches the mobilization cost is concentrated, because it occurs over a shorter distance.

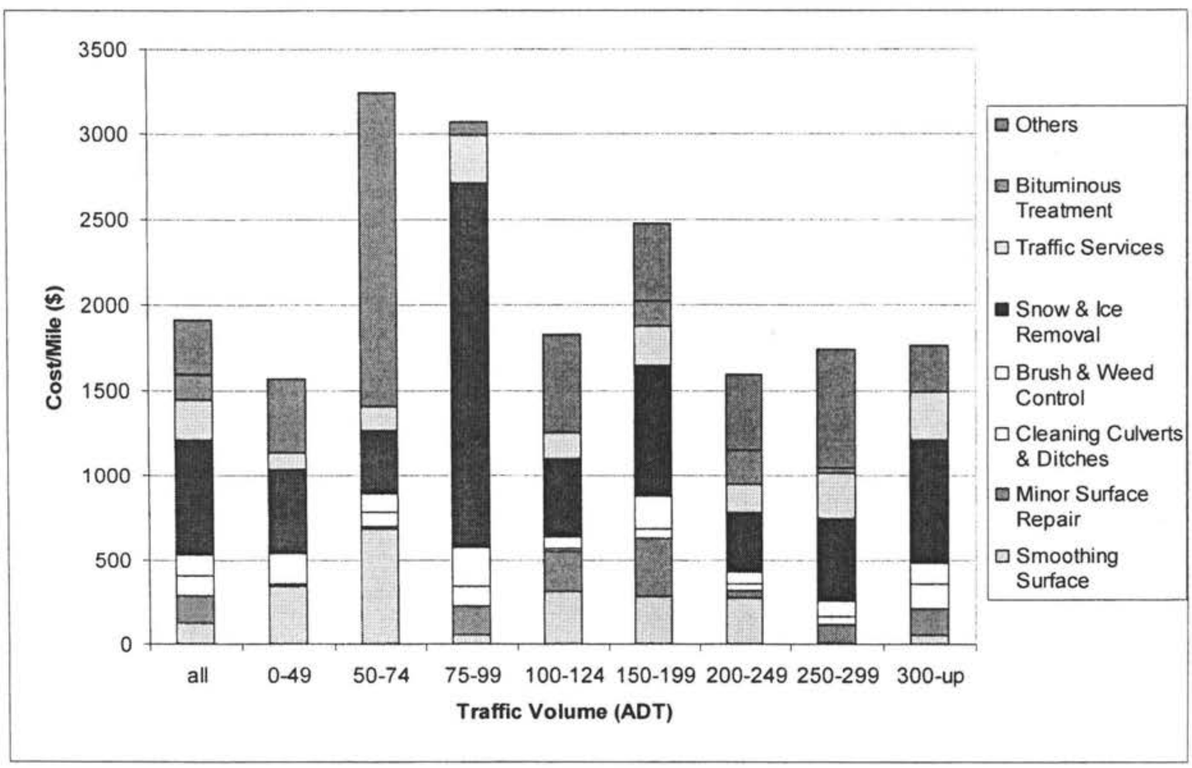


Figure 6. The average costs per mile for all the activities performed to maintain the paved roads of different traffic volumes in Kandiyohi County.

Meeker County

Meeker County is located in central Minnesota, with Litchfield as the county seat, and has an area size of 610 square miles containing 17.5 Townships. The county has a population of approximately 22,000 citizens and is growing slowly. There are 275 miles of CSAH Roads within the county, of which 250 miles are paved and the rest are gravel. The county has no County Roads under an agreement from 1969 with the Townships. Instead the county maintains 780 miles of Township Roads, of which 100 miles are paved and the remaining are gravel. The Townships are responsible for the capital costs for the roads, the purchase of gravel and constructing or upgrading the roads. Because of this agreement, Meeker County is able to maintain the roads at an extremely low rate compared to the rest of the counties in Minnesota. The costs to maintain the roads in Meeker County were reviewed, but the costs are not combined with the costs from the other counties since they will tend to lower the costs when an average is taken. In other words, these costs will be treated like an outlier, and considered separately.

The costs to maintain the paved roads in Meeker County can be found in Table 10; the average cost per mile is $634 ± 135. Also included in Table 10 is the number of road segments and total miles of road for each traffic volume range. More than 70% of the costs to maintain a paved road in Meeker County come from the activities found in the Routine Maintenance category. The majority of the remaining 30% of the costs come from a few activities found in the Repairs & Replacements and Betterments categories. The activities contributing significantly to these costs are *resurfacing* and *culverts, bridges, & guardrails* from the Repairs & Replacements category and then the cost contribution from the Betterments category is spread relatively even throughout the activities found within that category. A further break down of the costs associated with the Routine Maintenance category is shown in Table 11.

Table 10. Average maintenance costs per mile for paved roads in Meeker County.

Traffic Volume	Routine Maintenance	Repairs & Replacements	Betterments	Special Work	Total Cost/Mile	# of Road Segments	Miles of Road
all	$460	$75	$99	$0	$634	155	989
100-124	$439	$7	$7	$0	$453	3	4
150-199	$453	$0	$0	$0	$453	8	31
200-249	$508	$107	$32	$0	$648	25	127
250-299	$525	$151	$6	$0	$682	14	98
300-up	$437	$72	$151	$0	$660	95	725

Table 11. Average costs per mile for Routine Maintenance activities on a paved road in Meeker County.

Traffic Volume	Smoothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Sub-Total Cost/Mile
all	$12	$158	$93	$48	$39	$110	$460
100-124	$85	$75	$1	$15	$100	$163	$439
150-199	$1	$156	$116	$23	$31	$126	$453
200-249	$3	$251	$111	$42	$33	$68	$508
250-299	$1	$264	$91	$58	$17	$94	$525
300-up	$15	$122	$85	$54	$44	$115	$437

On average, for all the paved roads in Meeker County, the primary activities providing a significant role in determining the cost per mile for the Routine Maintenance category are *minor surface repair*, *traffic services*, and *cleaning culverts & ditches*. These three activities make up around 75% of the $460 ± 95 cost per mile for Routine Maintenance; however, recall that Meeker County has a unique arrangement for maintaining the roads within the county. Since Meeker County maintains the CSAH and Township roads (no County roads exist), they are apparently able to perform these activities in an inexpensive manner on a cost per mile basis.

A graphical representation of all the costs per mile associated with maintaining the paved roads in Meeker County is shown in Figure 7. In this figure, it is evident that nearly 75% of the costs in maintaining a paved road in Meeker County result from the activities found in the Routine Maintenance category, which includes the first six listed activities. Figure 5 also provides a slight indication that the cost per mile of a paved road does increase as the traffic volume increases. The costs remain relatively constant for the most part, but do increase over the increasing traffic volumes on the paved roads in Meeker County.

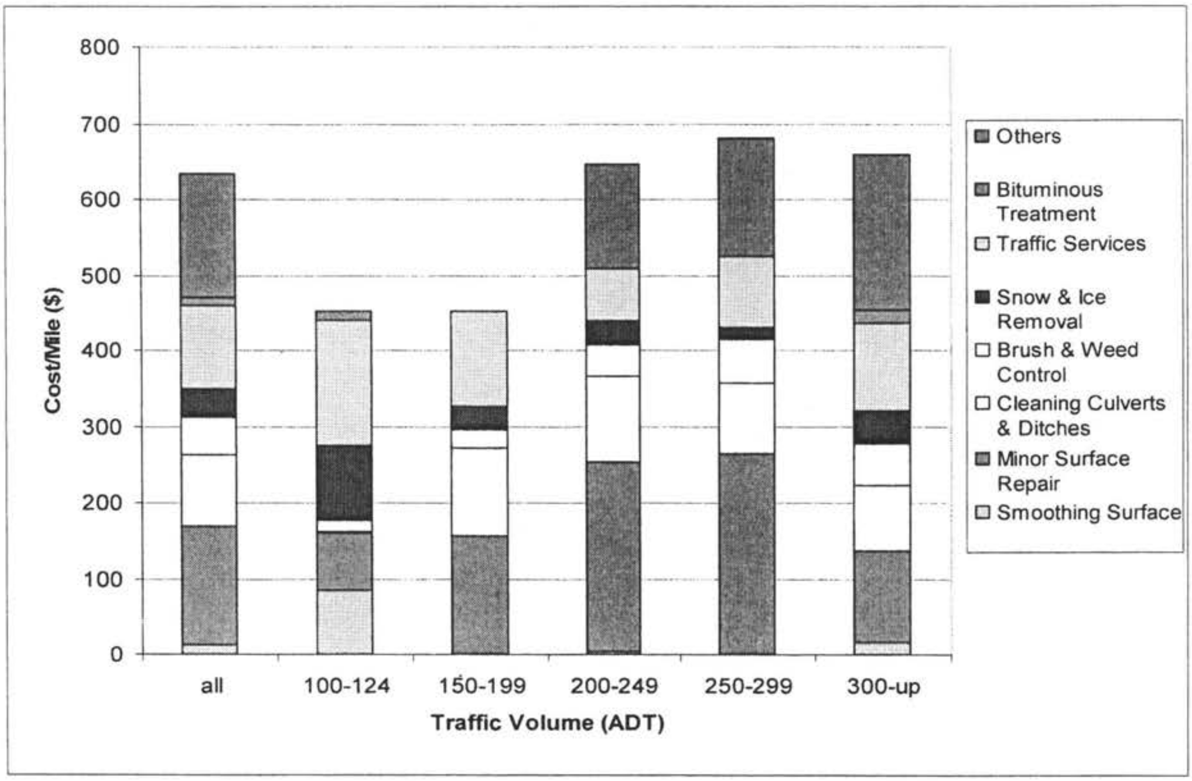


Figure 7. The average costs per mile for all the activities performed to maintain the paved roads of different traffic volumes in Meeker County.

Counties Compared and Combined

Review of a combined analysis of four counties, Aitkin, Benton, Blue Earth, and Kandiyohi, shows there is a wide range of costs per mile to maintain a paved road. Note these four counties were selected for further analysis because they had the most complete cost data in their annual reports and Meeker County was omitted from further analysis because of its special agreement with its Townships for maintaining their roads. These costs include all activities required to maintain roads and range from as little as $1917 ± 179 per mile to more than double that, \$4356 ± 566 per mile. A review of the activities that fall under the Routine Maintenance category shows the cost per mile ranges from \$1445 ± 123 to \$2405 ± 255. Table 12 provides a comparison of these costs for all four analyzed counties. Even though the total cost for the Routine Maintenance category varies by a little under one thousand dollars, this is a good value to use when comparing the maintenance costs per mile from one county to the next. This is because the activities performed in the Routine Maintenance category are performed by every county with close to the same frequency and scale of operation.

Table 12. A comparison of the average costs per mile for the Routine Maintenance activities for the four combined counties.

County	Smoothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Sub-Total Cost/Mile
Aitkin	\$43	\$226	\$87	\$178	\$1048	\$530	\$2112
Benton	\$52	\$246	\$43	\$169	\$572	\$406	\$1488
Blue Earth	\$135	\$728	\$71	\$325	\$843	\$303	\$2405
Kandiyohi	\$121	\$166	\$118	\$122	\$684	\$234	\$1445
All Four	\$97	\$389	\$79	\$212	\$767	\$344	\$1888

Upon examining Table 12, it is evident that the costs per mile for the *smoothing surface* and *cleaning culverts & ditches* activities are relatively small when compared with the other maintenance activity costs. The *smoothing surface* activity involves work primarily associated with maintaining an aggregate road, and so those costs should be relatively small for a paved road and can be ignored. As a result of the *cleaning culverts & ditches* activity occurring no matter what the road surface, there is no savings in money from one surface type to the next and thus these costs can also be ignored.

The costs associated with *minor surface repair* are important because they include activities related to fixing minor problems with the surface of a bituminous road. These include activities like patching potholes, filling and sealing cracks and any other activities, minor in nature, that are performed to repair the road surface. The cost per mile for this category should be higher for a bituminous (paved) road surface than for a gravel road surface. Therefore, it is important to quantify these costs when estimating the cost of maintaining a paved road.

The costs per mile for *minor surface repair* ranged from $166 to $728, this difference might result from the difference in age of the pavement to volume and type of traffic on the paved surface. The older a pavement, the more likely *minor surface repair* activities are to be performed each year. This is because the binder is becoming aged and oxidized, thus there is more fatigue damage that causes cracks in the pavement. The pavement may not be in sufficiently poor condition to warrant a major resurfacing or rehabilitation project, but the road must be maintained to provide a safe and smooth traveling surface, so many *minor surface repair* activities are performed. With more traffic on a road, the pavement will experience more loading, flexing, and fatigue. This damage can be exacerbated by heavy vehicles such as, semi-trailers and heavy farm equipment. Roads that primarily serve residential areas or are used to access lakes and cabins typically experience very few heavy loads; possibly a garbage truck once or twice a week and an occasional delivery truck that travel at lower speeds, so these roads experience little fatigue from heavy loads. However, these roads usually have a high volume of traffic from cars, suvs and pickup trucks that can cause some wear and tear on a paved road.

The remaining activities in Table 12 occur on gravel roads as well as bituminous roads; however, these costs are thought to be higher for bituminous roads than for gravel roads. This is because of two things: (1) Road users expect a higher level of service for a bituminous road compared to a gravel road (especially *snow & ice removal*). (2) More operations or work activities occur on a paved road than an aggregate road for the remaining cost activities. Costs for *brush & weed control*, which range from $122 to $325 per mile, are higher on a paved road because vegetation is kept cut back further from the edge of the road. This is because of the increased speeds on a paved road, thus drivers need an increased sight distance along the road and clear zone for accidents. Also, cars are more likely to drive along the edge of a paved road, rather than down the middle as they usually do for a gravel road, thus vegetation needs to be kept clear on the sides so as not to impede the vehicle's operation.

The cost for *snow & ice removal* is much higher on paved roads because more time is spent plowing them. Crews plowing snow make multiple passes with a snowplow truck on a paved road to clear the surface of snow, while on a gravel road only two passes occur to open the road to traffic. Also, sand and salt is placed on paved roads, at least on curves, hills, and at intersections, if not on the entire road. While on gravel roads sand and salt is rarely used, if at all, because travel speeds are slower and the aggregate may be protruding through, providing additional traction. These materials are placed on paved roads to aid in the melting of snow and ice and to improve traction in the absence of bare pavement, to improve safety on the road.

The reason the cost per mile for the *snow & ice removal* activity differs from one county to the next is because different areas of Minnesota receive different amounts of snowfall throughout the year. Costs for this activity ranged from $572 to $1048 per mile for Aitkin, Benton, Blue Earth, and Kandiyohi Counties. The counties farther north typically receive more snow, or at least are more likely to receive snow earlier and later in the year, thus increasing the chance for more snow, in comparison to the counties in southern Minnesota. Also, the snow plowing policy that a county has with regard to when the crews go out and for how long they stay on the roads will have an influence on the costs. Some start plowing with as little as 1 inch of snow while others wait to plow until there is about 3 inches of snow. Crews typically work a 10 to 16 hour day and then come back the next day to perform any additional work needed. Whether or not bare pavement is required varies and dictates how much time is spent clearing roads. Requirements range from mostly bare pavement, to only bare pavement required in the wheel tracks, to intermittent bare pavement required. Much of the bare pavement issues are dictated by the functional classification of the road and the amount of traffic present. Those roads with higher volumes of traffic and considered as major arterials have a more stringent bare pavement requirement than the roads with low traffic volumes that are classified as minor or local roads.

For *traffic services*, costs are higher because there are more signs required along a paved road and the road, depending on the type of improvement and the philosophy of the governing agency, is often striped with pavement markings. More signs are present to identify the road, upcoming junctions with other paved roads, speed limit and curve signs are posted more frequently, and delineators and arrows are posted around curves. Also more, no passing signs and other warning and information signs are posted on a paved road in comparison to an aggregate road. Finally, luminaries are typically placed at paved road intersections to increase visibility and safety, this cost and maintenance occurs under this activity.

The average costs per mile for this final activity, *traffic services*, listed in Table 12 ranged from $234 to $530. An explanation for the difference in these costs is difficult, but it may be a result of more striping of the pavement each year from the paint being worn off during the plowing operations for those counties receiving more snow. This may also lead to inadvertently destroying more signs and other marking devices that need to be replaced each year, but this is pure speculation.

The average cost per mile to maintain a paved road for Aitkin, Benton, Blue Earth, and Kandiyohi counties combined is shown in Table 13. Also listed are the number of road segments and the total miles of road for each traffic volume range. Again, Meeker County was not included in this portion of the analysis because of their unique situation in road ownership and maintenance of the roads within the county. After looking at Table 13, it is evident that a little more than 55% of the costs to maintain a paved road come from the Routine Maintenance category, with about 30% and 15% from the Betterments and Repairs & Replacements categories, respectively. The majority of the costs in the Betterments category come from the *bituminous treatments* activity. If the costs for the Betterments category, $914 per mile, are omitted since these activities are primarily construction activities performed to extend the service life of a pavement, then the Routine Maintenance and Repairs & Replacements categories contribute 77% and 22% of the costs to maintain a paved road, respectively.

Since the majority of the costs to maintain a paved road come from the Routine Maintenance category, a break down of the costs for the activities associated with this category is provided in Table 14. The average cost per mile to perform the activities in the Routine Maintenance category on a paved road is $1888, with the majority of the costs coming from four of the six maintenance activities. Those activities are *snow & ice removal*, *minor surface repair*, *traffic services*, and *brush & weed control*. The first two activities are necessary for providing a safe smooth traveling surface while the third activity provides direction and information to keep road users safe and the final activity works to provide a safe area surrounding the road area.

Table 13. Average maintenance costs per mile for paved roads in the combined counties.

Traffic Volume	Routine Maintenance	Repairs & Replacements	Betterments	Special Work	Total Cost/Mile	# of Road Segments	Miles of Road
all	$1888	$528	$914	$12	$3341	1192	6677
0-49	$1846	$306	$195	$0	$2347	36	18
50-74	$1530	$593	$748	$0	$2871	31	37
75-99	$1813	$597	$1346	$26	$3783	50	132
100-124	$1591	$576	$1036	$3	$3207	48	149
125-149	$1584	$548	$1606	$13	$3751	59	204
150-199	$1813	$463	$1067	$3	$3345	110	421
200-249	$1346	$456	$739	$7	$2548	96	600
250-299	$1617	$414	$1083	$18	$3131	91	545
300-up	$1871	$536	$721	$15	$3143	531	4435

Table 14. Average maintenance costs per mile for Routine Maintenance activities on a paved road in the four counties combined.

Traffic Volume	Smoothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Sub-Total Cost/Mile
all	$97	$389	$79	$212	$767	$344	$1888
0-49	$203	$294	$36	$157	$818	$338	$1846
50-74	$173	$139	$21	$243	$685	$269	$1530
75-99	$166	$260	$81	$187	$831	$288	$1813
100-124	$173	$348	$15	$138	$652	$265	$1591
125-149	$177	$280	$16	$205	$645	$260	$1584
150-199	$168	$388	$39	$230	$704	$283	$1813
200-249	$136	$233	$44	$165	$512	$256	$1346
250-299	$83	$245	$50	$189	$705	$344	$1617
300-up	$48	$424	$91	$209	$725	$373	$1871

Figure 8 provides a graphical representation of the costs for all the activities associated with the maintenance of a paved road. It is quite evident that the activity most closely influencing the average cost per mile for the various traffic ranges is the *bituminous* *treatments* activity. However, since this activity is not performed on a yearly basis for each mile stretch of road, its contribution to the annual maintenance cost per mile of a paved road is a bit misleading. If that cost is ignored, then the activities which are major contributors are the first six activities listed, those from the Routine Maintenance category.

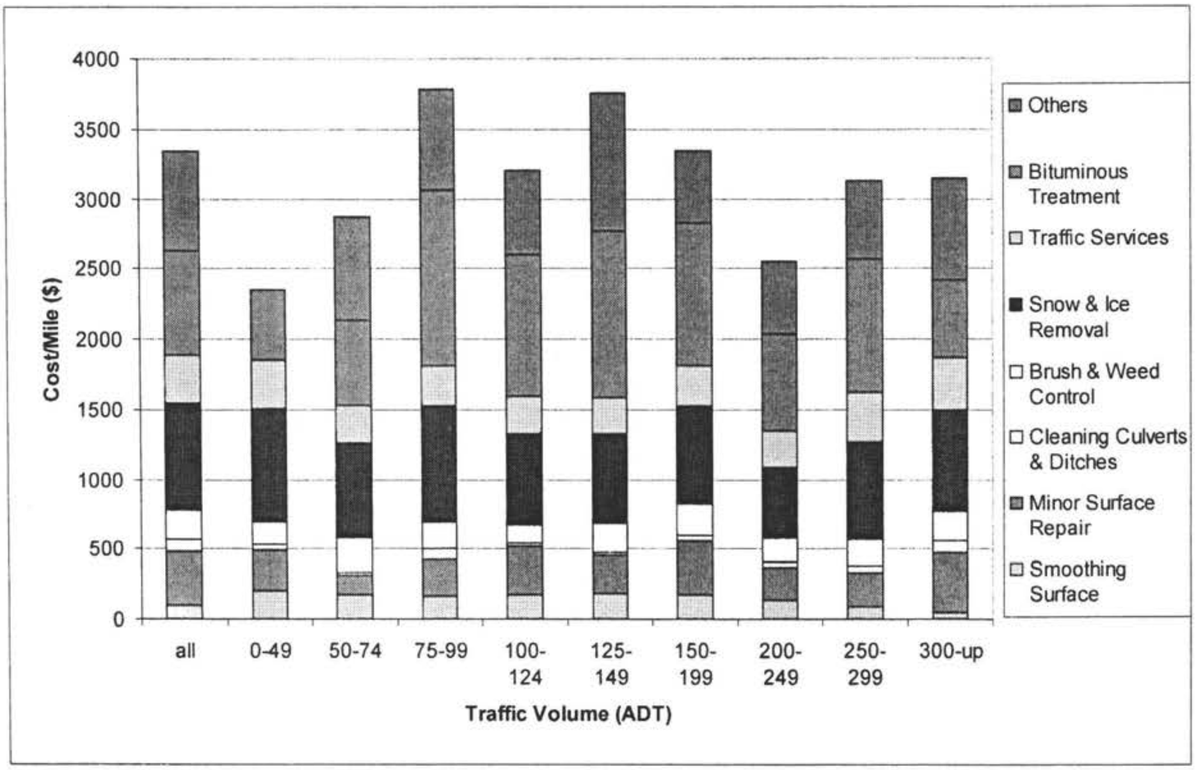


Figure 8. The average costs per mile for all the activities performed to maintain the paved roads of different traffic volumes for the four combined counties.

Figure 8 also shows that as traffic volumes increase, the cost per mile remains fairly constant. This suggests that the cost to maintain a paved mile of road is independent from the amount of traffic present on the mile stretch of road, contradictory to what was assumed at the beginning of this study. Upon further review, this actually does appear to make sense because a paved surface has all the material bound in place, and as long as the road is built structurally for large traffic volumes it will perform just as well with the lower traffic volumes. Conversely, if the road is built structurally for low volumes and lighter amounts of traffic, then it should begin to deteriorate as traffic volumes and loads increase.

A comparison of cost per mile for each year from 1997 through 2001 is shown in Figures 9 and 10 for Aitkin, Benton, Blue Earth, and Kandiyohi Counties. Figure 9 provides a comparison of the cost per mile for all activities performed to maintain a paved road over a five year span. Figure 10 shows the variation in cost per mile over a five year time span of the category that contributes the most to the cost to maintain a paved road on a yearly basis: Routine Maintenance. Not only is it evident in both of these figures that the costs per mile to maintain a paved road vary from county to county, but the costs also vary from year to year within one county. This variation from year to year is a result of different amounts of work being done within an activity and somewhat to seasonal variations from year to year, such as heavy rains or snow causing flooding and washouts or more plowing and salting, respectively. Another activity that varies in the amount performed year to year is *bituminous treatments* because not every road is on the same cycle for work to be performed, so the money spent for this activity varies each year.

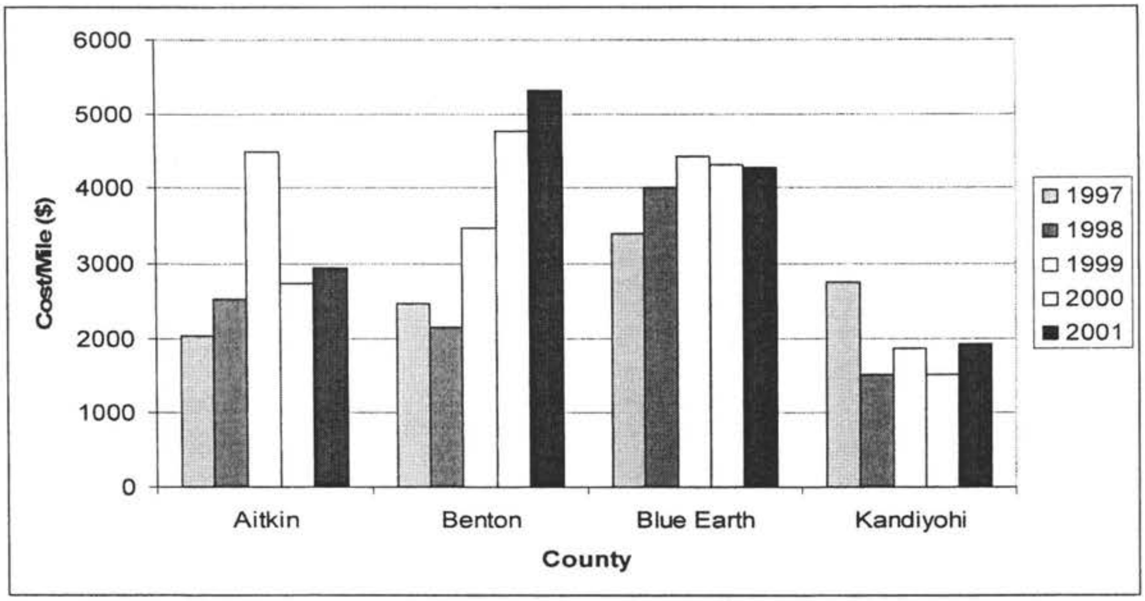


Figure 9. A comparison of the average cost per mile, for all maintenance activities, to maintain a paved road in four different counties over a five year time span.

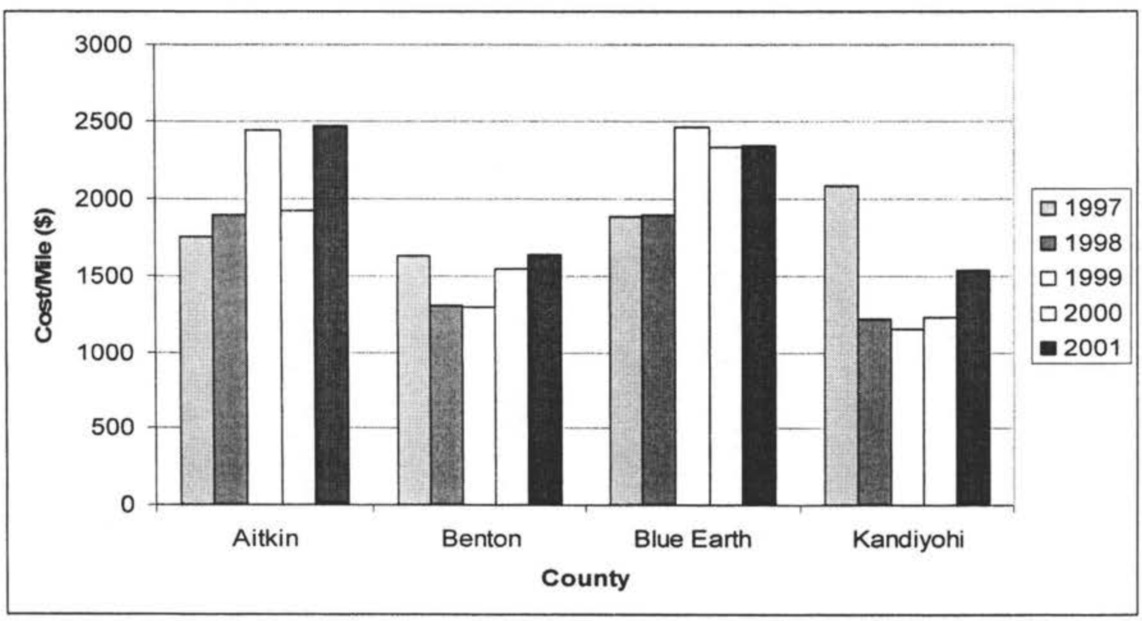


Figure 10. A comparison of the average cost per mile for the Routine Maintenance activities performed to maintain a paved road in four different counties over a five year time span.

Options for Upgrading a Gravel Road

There are several options to choose from when deciding to upgrade an aggregate road to a paved road or some kind of a bound surface. The options for upgrading to a paved surface range from completely regrading and improving the roadway geometry down to lightly surfacing the roadway and making no improvements to the geometry. The choices in between these extremes include doing minor grading work to improve the most troublesome horizontal and vertical curves; only improving drainage; and adding, modifying or improving the base material to improve the structural capacity of the road. The amount of grading work to be performed depends on the type of surface for the upgrade and source of funding. Various funding sources require different specifications for an upgrade. Some surfacing options include a traditional full depth concrete (PCC – portland cement concrete) or hot mix asphalt (HMA – or bituminous) surface, only three inches of hot mix asphalt placed on the existing roadway, and an Otta Seal or other thin surfaces placed on the existing roadway or a modified base. More information on the use of Otta Seals, chip seals, and oil gravel roads can be found in Greg Johnson's paper, "Minnesota's Experience with Thin Bituminous Treatments for Low-Volume Roads" (6).

For all the surfacing options, even those that are not listed here, having a good base is key to the success of the road surface. A good base means having the ability to structurally support the heavy loads and increased traffic that will be traveling over the surface. The base must drain water properly so as not to weaken the subgrade. Gravel roads do not typically have a strong base or surface course. As a result of this, gravel roads rut and deform more easily, but are also easier to reshape and regrade back to the original condition. When placing a traditional full depth concrete or hot mix asphalt pavement, the road is typically regraded, even if only minor grading work is performed. During this process new drainage structures are placed and the road geometry is graded to meet necessary design specifications. During the grading process appropriate base material is hauled in if necessary and as specified in the construction plans to ensure a stabilized, easily drained, roadbed.

PCC roads are usually selected for situations where there are extremely high traffic counts and loads anticipated, much higher than those typically found on a Minnesota County or CSAH Road. Anticipated heavy truck traffic and loads are another common justification for using PCC pavement. The areas where such heavy traffic is likely are agricultural areas where several semi-trailer loads per day are used for transporting materials to processing plants or distribution facilities. When there are only occasional heavy loads on a paved road, then a 9-ton designed HMA road is usually considered to be sufficient (4). Most of the county personnel interviewed in this research project indicated that if they are paving a road and the traffic count is above 150 ADT or predicted to increase to that level or greater, they then use a 9-ton design for HMA. If the traffic count is less than 150 ADT and predicted to remain fairly constant, then a 7-ton design is sufficient.

An alternative to a 7 or 9-ton HMA design is the placement of approximately two inches of Class 5 rock and three inches of bituminous mix (4) over the existing gravel roadway. The existing roadway should be in good condition and have a strong, stable base. This surfacing method provides little structural support, but does provide a smooth, hard surface that seals the base and subgrade from moisture penetrating through the top. The placement of the two inches of Class 5 rock on the existing roadway works to increase the structural capacity of the newly paved surface. If a road experiences significant amounts of residential traffic, either constantly or intermittently, causing the road to be maintained each week to prevent potholing and washboarding, then placing a surface of this type might reduce maintenance costs. Depending on how wide the road top was constructed and the amount of structural support provided by the additional two inches of Class 5 rock and the existing roadway, the new pavement could be striped or not. This is because structurally stronger roads allow for traffic driving on the edges of the pavement, which happens when a road is striped. Speed limits could be posted in accordance with the allowable speed based on the design of the existing horizontal and vertical curves since there is no regrading involved in this surfacing option. The idea of placing a road surface of this nature is not to increase travel speeds but to provide a surface that is smoother and easier to maintain. Since the primary traffic is residential vehicles traveling to and from their home there should be no need for a high speed road. Improving a gravel surface to a bound surface without improving the geometry of the road is similar to the approach used by the United States Forest Service for some of their roads (2). The intent is not to increase vehicle speed, but improve the road surface and reduce maintenance.

One additional option for providing an improved bound surface is the placement of an Otta Seal. Otta Seal, sometimes referred to as road oil or blotter seal, is a surface that is created when well-graded aggregate is placed over a soft binder. This aggregate is then rolled in to the binder film creating a relatively thin bound surface that seals water out of the base. Typically, when constructed, two lifts are placed to provide a surface within an overall thickness about one and a quarter inches. Since this is a relatively thin surface, a strong base is required. Otherwise, the traffic loads will cause the Otta Seal to break apart and fail. Before the Otta Seal is placed, the base needs to be smoothed and, if necessary, more base material must be applied to increase the structural capacity of the road. In addition, the road base may be stabilized with a treatment of calcium chloride. This surfacing option is appropriate for roads with traffic counts up to approximately 400 ADT, with occasional heavy loads from trucks or farm equipment (6).

Otta Seals are a relatively low cost surface treatment because locally available aggregates of modest quality may be used. Treatment costs average around $20,000/mile and have an expected service life of ten to fifteen years (6). Another reason this treatment is relatively low in cost is that a county may use its own forces and equipment to construct the surface. Along with having a low construction cost, the maintenance costs should be lower, since the surface no longer needs to be bladed and aggregate does not need to be hauled in each year to provide an adequate travel surface. Even though a bound surface is created with the use of an Otta Seal, there is no need to provide striping and other pavement markings because the road still has the look and feel of a gravel road to the casual observer. For this reason, road users should be encouraged to use travel speeds that are similar to those for gravel roads. By not striping or applying pavement markings to the surface of an Otta Seal road, traffic tends to concentrate towards the center of the road and away from the weaker edges. Otta Seals are a relatively new surfacing option being tried in portions of Minnesota; however, this surfacing has been used with success in Norway since the early 1960's (6). Since the use of an Otta Seal as a surface treatment in Minnesota is new, little information is available on the successfulness or costs in Minnesota.

Other surfacing options that are similar in nature to an Otta Seal include a double chip seal and an oil gravel surface, also known as a seal coat or Finn Road, respectively. The double chip seal can be placed on an existing aggregate base, which is structurally stable and strong. The chip seal used in this case is the same chip seal treatment used to extend the service life of a HMA pavement or bituminous road. Costs for the double chip seal are around $20,000/mile, with a service life expectation of six years, much like when a double chip seal is placed on regular HMA pavements (6). As long as a good base is present to provide the structural capacity of the road, the use of a double chip seal appears to be a viable candidate for a surface treatment to upgrade aggregate roads with light to moderate traffic volumes.

The oil gravel surface treatment is a mixture of asphalt oil and aggregate blended together much like a cold mix asphalt treatment and is then placed with the use of the types of pavers and rollers used in the construction of a traditional HMA pavement. An advantage to this surface is that excess amounts of mix can be produced and stockpiled for use in repairing the road; the mix remains workable long after construction. Costs for the oil gravel mixture are approximately $50,000/mile, with an expected service life of approximately six years (6).

Table 15 provides summaries of information on various construction and maintenance practices for the seven counties that were included in the interview process for this research project. Most of these counties seem to be performing these activities at approximately the same time intervals and using the same practices; thus it is likely that these activities are typical for most of the counties in Minnesota.

Table 15. A description of the construction practices and costs associated with paved roads for Olmsted, Waseca, Meeker, Blue Earth, Benton, Aitkin, and Kandiyohi Counties.

	Olmsted	Waseca	Meeker	Blue Earth
Crack Sealing	5-7 year cycle – before seal coating, use blow & go technique	Route and seal cracks	Do blow & go seal technique when cracks get to 1/2" size	5 year cycle
HMA Overlay	$110K/mile – 12-15 year service life	Expect 20 year service life	Very few overlays because of long life of original HMA	15 year cycle – do 2 overlays then CIPR & HMA
HMA Pavement	$350K/Mile – 9 or 10 ton design, 1' subcut (blend and replace), 1' base (class 5 rock), 6" of HMA (regrading included)	$225K/Mile for HMA & shoulder – new HMA (5834) is sawed & sealed (regrading included)	Use a 2360 mix at $100K/Mile – 9 ton design for 55 mph roads & 5 ton design for 30 mph roads	$150K/Mile – 9 ton road design includes 12" gravel & 4" of superpave, no grading
Seal Coat	5 year cycle at $5500/Mile, expect 3-5 year service life	Chip seal – applied 3-4 years after new HMA, then 7-8 year cycle	First typically 3 years after paving, then another few years later	$6K/Mile done on a 5 year cycle using pea rock or natural gravel
Regrading	$150K/Mile	$100K/Mile	$250K/Mile on avg. up to 350K/Mile for major realignment	$100K/Mile in flat open country – light grading
Other Treatments	CIPR – 15 year cycle, at least 4" then place 2 1.5" HMA lifts	After CIPR, place a 3" 2350 overlay	Placing a 3 ton design mix around lake roads – 3" of mix and 2" of class 5 rock	$60-80K/Mile – emulsion oil gravel

HMA – Hot Mix Asphalt CIPR – Cold In Place Recycling

Table 15. continued.

	Benton	Aitkin	Kandiyohi
Crack Sealing	During winter as needed	Do what they can in May, starting with newer pavements	4-7 year cycle – blow & go technique
HMA Overlay	15 year cycle on average	$20K/Mile 1.5" every 8-10 years, 3" every 15-20 years	$82.3K/Mile for 2" done on a 10-15 year cycle
HMA Pavement	$350K/Mile in sand base area $450K/Mile in clay base area – costs include grading	$115K/Mile – 4.5" HMA & 2" gravel, includes a 4' HMA shoulder	$392K/Mile – includes regrading, base, surface – expect 25 year life
Seal Coat	$8K/Mile when done	Not performed	Not performed
Regrading	$175K/Mile – depends on road	$175K/Mile on average – range from $129-250K/Mile	$175K/Mile – depending on terrain, soils, & work
Other Treatments	Full depth reclaim & overlay $90-100K/Mile	Thinking about Otta seal, but none yet because of poor soils	2-5 year cycle for shouldering & other activities, thinking about Otta seal

HMA – Hot Mix Asphalt CIPR – Cold In Place Recycling

Deciding Which Gravel Roads to Pave and When to Pave a Gravel Road

Deciding which gravel or aggregate road to upgrade using portland cement concrete (PCC) or asphalt cement concrete (ACC) or an alternate light surface is a difficult task for County Engineers and other Road Officials. This is especially true for roads with low traffic volumes and in a time of decreasing county budgets. A possible tool that may be used for assisting in this decision process is a road network/pavement management system. A road management system creates a database of information for all roads – when they were built, road and traffic classification, traffic volumes, design specifications, materials used, history of maintenance activities, and evaluation of the condition or performance of the road. The road evaluation needs to be performed objectively, thus a preestablished list of items to be evaluated and a method for assigning the ratings must be created. This allows for all roads of similar type to be rated in the same way to allow for comparison despite the differences in road type (eg. HMA vs. PCC). A road management system can also be used by a County Engineer or other Road Official to justify priorities for road improvements to the general public or to their Board of Supervisors.

The road evaluations need to be performed on a regular basis to keep the database current and allow for decisions to be made based on actual conditions. Depending on how large the road network is or the functional classification of a road, roads may be evaluated every one to three years. The evaluation of each road should probably be performed by more than one person at separate times to help reduce any bias one evaluator may have to a particular road. The evaluation should at least be executed by the same person each time to help ensure consistency in the rating of each road.

Along with a road management system, an overall paving policy should be established by the controlling agencies. The paving policy should cover items such as:

- At what traffic level do you begin to consider upgrading?
- What is the major traffic type – does a lower traffic volume of a certain traffic type justify an upgrade sooner or later?
- What is expected growth in area?
- Will an upgrade bring economic growth to area?
- What is the cost for upgrade?
- How much effort is required?
- What type of surface is desirable?
- Will road be brought up to current geometric standards?
- What safety issues need to be addressed?
- How does upgrade fit into existing road network within its own jurisdiction and surrounding jurisdictions?

In conjunction with the use of a road management system and having an established paving policy, a road rating worksheet can also be a valuable tool to help in deciding which roads to upgrade. The road rating worksheet can be based off information found in the road management system and answers to questions brought up by the preestablished paving policy. The rating worksheet can be used to assign point values to a road based on the answers to questions in the paving policy and the road management database. The point total for each road can then be used to rank the roads in order from highest to lowest priority for upgrading a road; a sample rating worksheet can be found in Appendix D. It would probably be best to have two different rating worksheets, one for helping in deciding which gravel road to upgrade to a paved surface and another worksheet for deciding which existing paved road may need improvement.

As stated in the Literature Review, the Kentucky Transportation Center put out a brochure, "When to Pave a Gravel Road" in April of 1988, using gravel as a generic term referring to either gravel and sand or crushed stone as the aggregate surfacing on the road (11). Their answer to paving a gravel road is a ten part answer. They suggest the controlling authority make the decision based on the following answers:

1) After Developing a Road Management Program.
2) When the Local Agency is Committed to Excellence.
3) When Traffic Demands It.
4) After Standards Have Been Adopted.
5) After Considering Safety and Design.
6) After the Base and Drainage are Improved.
7) After Determining the Costs of Road Preparation.
8) After Comparing Pavement Life and Maintenance Costs.
9) After Comparing User Costs.
10) After Weighing Public Opinion.

Information about when to pave gravel roads was collected during interviews conducted with personnel from the seven counties in Minnesota that were visited by the researcher. The decision making process and practices are summarized as follows.

When deciding whether or not to pave or upgrade a gravel road, Olmsted County personnel look at a combination of items related to the road specifically and the overall road network. Key factors in deciding include a combination of traffic volume and traffic type. Currently, the county usually paves when traffic volumes reach 500-1000 ADT.

Meeker County decides when to pave the roads using guidelines from the State Aid Manual – the road must have an ADT of at least 150 in order to be eligible to receive state aid funding for the upgrade. Also, the road needs to be upgraded to the State Aid Standards. Along with reviewing traffic volumes and traffic types, Meeker County also determines how the newly upgraded road will fit in with the rest of their road network, does the new road connect to an existing paved road or does it end on a gravel road.

Blue Earth County decides to pave the roads based on traffic volumes, the functional class of the road and other economical factors. The decision to pave a road is also affected by politics, as are many decisions made by governmental agencies. When traffic volumes are above 200 ADT on gravel roads, Blue Earth County cannot keep the road smooth. Also, large amounts of dust are created along the roadway, reducing visibility and causing safety issues for the traveling public.

Aitkin County usually paves the roads after traffic volumes reach around 200 ADT, but most of the decision on whether or not to pave a road is driven by the availability of funding, both for construction and for maintenance after construction. Along with considering traffic volumes, Aitkin County also considers the number of residences along the road, the functional classification of the road, safety issues (the number and type of accidents and their causes), whether or not the road is a part of an already improved county route, and the percentage of public land ownership when deciding whether or not to pave a road. When considering the number of residences along a road, Aitkin County also determines how many residences are year round or seasonal; the road will receive more use from more year round residences. For road classification Aitkin County considers if the road is an arterial road, a major or minor collector road, local road and whether or not the road dead ends. In addition, Aitkin County wants to determine the percentage of public land ownership because most publicly owned land will not be developed to bring in additional income to the county.

Currently, Aitkin County is using the available funding they have to maintain the existing pavement system and bridges. Any remaining money is used to upgrade roads based on their ranking in the priority rating worksheet that is used by the county. This worksheet assigns points to each road segment based on six different categories. The categories are essentially the items (mentioned above) that are considered when deciding whether or not to pave a road. The number of points a road may potentially receive are as follows: projected ADT (20 points), number of seasonal and full-time residences per mile (20 points), functional classification (10 points), part of larger improved route (10 points), sight distance/safety rating (10 points), and percentage of private land adjacent to road segment (10 points), a copy of this priority rating worksheet can be found in Appendix D.

Presently in Aitkin County, the road also has to be up to state aid standards in order for paving to occur. However, the County Engineer is considering the possibility of surfacing a road that does not meet state aid standards. He is not sure how people will react when driving on a bound surface when lower speeds are warranted because of the road geometry. The legal and moral issues regarding his obligations to ensure and provide a safe traveling surface to the public are playing an important role in the County Engineer's decision on whether to surface a road not up to state aid standards. If the surface treatment looks like a gravel road and is not striped, he thinks that perhaps road users will drive with a little more caution than they would if the road looked like a regular bituminous surfaced road.

Kandiyohi County paves the roads depending on traffic counts. If the traffic count is 150 ADT with projections for growth, decision makers usually begin to consider paving at that point. However, if the traffic count at 150 ADT is projected to remain fairly consistent, then they look at paving the road around 200 ADT. Besides looking at ADT counts, Kandiyohi County personnel also look at the road's functionality and how it ties in with the remainder of the existing paved system or with the paved system in the adjacent counties. Some times politics works its way into deciding which road will be paved, but usually the County Board of Supervisors listen to the recommendations of the County Engineer on whether a road should be paved or not.

Benton County has a gravel road pavement policy that is based mainly on the roads ADT count. However, they also consider the potential for economic development as a result of a road being paved, the cost to do the work, accident rates and other safety issues and other subjective matters.

Benefits from Upgrading a Gravel Road

The upgrading of a gravel road to a bound (paved or sealed) surface can be a significant cost for a county, especially if changes in the geometry of the road are required to bring the road to necessary standards before the upgrade can occur. However, despite the initial costs, there are benefits to upgrading a gravel road. These benefits include reduced dust, smoother surface, safer surface, improved vehicle efficiency, reduction in maintenance activities on the upgraded road, reduction of traffic on surrounding roads, and an increased tax base. Some of the benefits result in a direct savings for the county budget, while other benefits indirectly affect the county budget.

After a road is upgraded to a bound surface, vehicles create little dust; this is primarily an indirect benefit to the county. Since all of the aggregate material is bound in place, the bound aggregate breaks down more slowly than the loose aggregate, producing very little, if any, dust. With no dust coming from a paved road, surrounding homes are kept cleaner and the air is free of dust particles. As a result of less dust being inside and around a house and fewer dust particles in the air, the living conditions for people along a paved road are improved by possibly reducing asthma, allergy and breathing related health issues. Since less dust enters a house, the homeowner spends less time cleaning; this is also a savings for the homeowner. Dust free roads are also a benefit to the environment by not polluting the air, as mentioned previously, and by not polluting waterways with dust and other particles that may be blown into the water. Also, surrounding vegetation is not caked in dust, so they are better able to grow to produce food and improve the environment.

On dust free surfaces, road users are able to see ahead of them to be alert for oncoming traffic and other roadside hazards such as: animals along the road, ditch, and surrounding fields, slow moving farm machinery, and pedestrians. Since dust is not being produced, the homeowner who may have been spending money on calcium chloride or other dust suppressants, now no longer needs to spend that money. This is both a positive and negative benefit to the county. The positives are that the local jurisdiction is not possibly degrading the environment by placing these dust suppressants, even though they appear to be safe for use. Also, the homeowner now has more money to spend elsewhere, helping the economy. However, the businesses supplying and placing the dust suppressants on dusty gravel roads are now receiving less business, which hurts the economy, a negative to eliminating the use of dust suppressants at that location.

A smoother and safer road surface is created by upgrading an aggregate road. No longer will a driver have the sensation that their car is floating across the road, or that they are "driving on marbles," giving the sensation that the driver has little control over their vehicles travel. Instead drivers will feel more confident that they have control over their vehicles. The paved surface is not susceptible to washboarding and potholes, which creates a rough driving surface causing tires to loose contact with the road surface. If a vehicle needs to stop suddenly it will not skid as far as it would slide on a loose gravel surfaced road. In addition, drivers will not be subjected to soft muddy surfaces that can "pull" vehicles in unexpected directions, making steering difficult.

Better vehicle fuel efficiency is obtained when a vehicle operates on a smooth hard surface as opposed to a loose gravel surface. As stated, hard surfaces create a smoother ride since they are less susceptible to developing potholes and washboarding, which then reduces the amount of wear and tear on a vehicle's tires, shocks, and struts. In addition, since there is little dust produced on a paved surface, the filters (air, fuel, and oil) on vehicle are kept cleaner, improving fuel efficiency and operating costs. The reduced wear and tear on a vehicle and the better fuel efficiency leads to reduced operating costs for the traveling public's vehicle. The smoother surface also leads to increased travel speeds, resulting in less travel time spent in the car (less time the car is operating, a savings to the vehicle owner) and more time at work (a benefit for the employer) or more free time (a benefit for the people traveling on the road). These savings are not directly felt by the county budget, but indirectly the county is benefited with more money being available to be spent within the county's economy. However, if the road geometry is not improved, there are increased possibilities for more serious accidents if speeds are increased on the bound surface road.

When upgrading a road from one surface type to another, the costs of several different maintenance activities could decrease, remain the same, and/or increase. However, the potential savings that occur from upgrading the road can offset the increased expenses that might occur for some maintenance activities. When a gravel road is upgraded to a hard surface, there is no longer a need to grade (smooth and blade) the road. A significant cost savings from upgrading a gravel road results because the local jurisdiction no longer needs to haul gravel to the road each year for resurfacing needs. By no longer needing to haul gravel to a road year after year, the governing agency is reducing the demand on the gravel suppliers. If the demand for gravel is reduced, obviously, less gravel needs to be quarried from the ground and the costs for gravel may go down, resulting in a savings to the county for resurfacing costs of the other gravel roads. This is simple supply and demand economics, if the demand is low and the supply remains the same or even goes up because less is being used, the price for the material should then go down. However, there may be other factors at the quarries that may affect the cost but not be known to the public. Another maintenance activity that can directly benefit a county is no longer needing to purchase and apply dust suppressants. Not only do you not need the dust suppressant, but the county would then no longer need the equipment used for application. The reduction in maintenance costs or activities is a direct benefit to the county. Those monies saved in maintenance activities can be spent elsewhere to provide better service across the entire county's road network.

Paved roads can reduce traffic on the surrounding roads, thus reducing the maintenance activities for those surrounding roads, by drawing some of the surrounding traffic to the improved road. Here the old adage, "if you build it, they will come," applies. This means, that people may drive a few miles out of their way to travel on a paved road instead of driving on a gravel road, especially if the paved road takes them to their final destination. People do this because they know the trip will be faster and smoother, which will be a more pleasant experience for them. If the public has a more favorable or pleasant experience driving to town on a paved road, they are more likely to take quick multiple trips a week into town to run their errands, instead of taking one or two trips to town a week. By taking more trips into town, the public will be spending more money on gas and other things, thus stimulating the county's economy to grow and improve the tax base, an indirect benefit to the county. This benefit of more trips to town and stimulating the local economy also has a down side, more fuel and natural resources are used and more pollution is created from vehicle exhaust.

An additional possible direct benefit to the county resulting from the upgrading of a gravel road is an increase in the tax base for the county. This can come in two ways: either through new development along and near an upgraded road or from increased assessed property values along the improved road. Development usually follows an upgrade in services to the public – including upgraded roads. The paved road is providing a smooth, safe, and reliable traveling surface allowing goods and people to get to and from their place of business and residence. The new houses and businesses built along a paved road bring in more property tax revenue money to the county as well as improving the overall livelihood of the county's economy.

The benefit of increased tax income from increased assessed property values is explained in the following paragraphs. People want to live on a hard surfaced road, as is evident from the many requests a county receives to pave a gravel road. This is because, they want the amenities of "city life," smooth paved roads, but they still want the experience of living in "the country." For this life, people seem to be willing to pay more for a house on a hard surfaced road compared to the same house on a gravel road; this seems particularly true for people moving from urban areas. As a result of a higher retail value for a house on a hard surfaced road compared to a gravel road, the assessed value for the house should also be higher on the hard surfaced road. Based on conversations with realtors, county assessors, and appraisers, the difference between the assessed values of a house on a hard surfaced road compared to that of a gravel road is probably only about two thousand dollars. This small difference is hard to quantify with actual market data since there are so many other factors that vary between houses and very few properties are alike. Granted this difference in assessed values is not a substantial amount of money, but when considered over time and for every house on a paved road, the additional revenue to the county starts to be noticeable. During the times of tight county budgets, any additional income is very valuable.

By assessing properties on bound surfaced roads at a higher rate than properties on a gravel road, an additional tax base would be available to a county that does not perform this practice of assessing properties differently based on the road surface they are located along. Thus, when a road is upgraded to a hard surfaced road from a gravel road, the county highway maintenance department is saving money as a result of the decreased maintenance costs for an improved road surface and they are increasing the income from property taxes for the county with the improvement to the road surface. For example, say there are 10 houses within a mile of each other on a hard surfaced road. If each one is assessed $2000 more per year, that is an extra $20,000 of assessed value per year compared to the same stretch of road as a gravel surface. If the life of the hard surfaced road is expected to be 20 years, that is an extra $400,000 of assessed value per year. If the county tax rate is 18% or $18 for every $1000 of assessed value, this leads to an additional income to the county over the 20 year time frame of $72,000. Granted this additional income is small in the scheme of county budgets, it could be used to help recover the initial investment by the county in upgrading the road, or it could be placed in a separate account to fund future projects. When every hard surfaced road in the county is considered, the significance of the increased assessed values begins to be noticeable. If the county has 250 miles of hard surfaced roads, that would be an addition of $18 million over 20 years or $900,000 each year to the county budget. The actual amount of additional income a county could receive is yet to be determined, but it may be significant enough that it offers a way to finance a road upgrading project or the amount may be very little. No matter what the amount of additional income is, the county would be receiving additional income.

For a county that already assesses property values differently based on the road surface in front of the property, the more roads that are surfaced every year, the more income they would see from increased assessed property values. If there are 10 houses per mile stretch of road, the county tax rate is 18%, and the difference in assessed value for a house on a hard surfaced road compared to a gravel road is $2000, then the county would receive an additional $3600 of tax money for that mile stretch of road per year (as long as the road remained a hard surfaced road). If the county were to upgrade 10 miles of road in one year, they would then receive an additional $36,000 in tax revenue for that year and each additional year that road remained a hard surface. In addition to increasing the tax revenue from upgrading the gravel road, overall maintenance costs for the road will be reduced; another benefit for a county, especially during the current tight budgets.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The cost per mile to maintain a paved road varies from one county to the next because of county maintenance practices, weather and environmental conditions, and the age of the road. One maintenance practice that varies is *snow & ice removal*, because each county has different requirements for their snow and ice removal policy, which dictate how long the county forces work to clear the roads. These policies range from requiring bare pavement to intermittent bare pavement on the roads. Locations in the state that receive more snowfall have a higher maintenance cost per mile because of more *snow & ice removal* activities being performed to remove the additional snow. Two other maintenance activities that vary are *bituminous treatments* and *minor surface repair*, because the amount of work performed for these activities is related to the age of the bituminous road. Older roads require more service because the bituminous material has oxidized becoming more brittle and more susceptible to cracking and thus needing to be sealed or filled.

Based on this research it is expected that the cost per mile to maintain a bituminous road ranges from about \$1900 to \$4300, with the average cost being around \$3300. These costs include all maintenance activities, previously listed in Table 1, that are typically performed when maintaining a paved road. The costs for the activities found in the Routine Maintenance category are expected to range from \$1400 to \$2400 per mile, with an average cost around \$1900 per mile. This cost range includes the following activities that occur on a yearly basis when maintaining a paved road: *smoothing surface*, *minor surface repair*, *cleaning culverts & ditches*, *brush & weed control*, *snow & ice removal*, and *traffic services*.

Even though many of the activities performed to maintain a paved road also occur on an aggregate road, some are performed with greater frequency or include more work items for paved roads. Thus, these activities need to be considered when estimating the cost per mile to maintain a paved road in a safe manner for the traveling public. These key activities contributing the most to the cost per mile to maintain a bituminous road include *minor surface repair*, *snow & ice removal*, *traffic services*, *brush & weed control*, and *bituminous treatments*. These first four activities occur every year and are higher on bituminous roads than on gravel roads because a greater level of service is expected by road users when they are driving on a bituminous road. Speeds are higher on bituminous roads, so for safety reasons, the roadsides need to be kept clear of more brush and weeds and the roads need to be kept in a smoother condition. In addition, more signs are posted to identify the road and intersecting roads, curves, no passing zones and other potential hazards.

The costs for *bituminous treatments* do not occur every year, depending on the road and activity, these treatments occur every 5 to 20 years and are more of a preventative maintenance action designed to extend the service life of the paved surface by providing a new wearing course. Since the time of application for these activities varies and the activity provides a new wearing surface, these costs should be considered at the time they occur as incremental investments in the pavement asset. Table 16 provides a summary of the occurrence of these treatments, their cost per mile and the cycle time for when they may occur.

Since the cost to construct a HMA road is relatively expensive for upgrading a gravel road with little traffic, other surface options need to be considered that would be less expensive to build, yet still provide a sealed, smooth, and dust free surface. This leads to the use of thin surfaced roads, because they provide a bound surface similar to that of a traditional pavement that seals out moisture and reduces maintenance costs; however, they provide no structural support to the road. Either placing an Otta Seal, Double Chip Seal, or Finn Road on a road with an established structurally sound base or building up and improving the base with additional rock would provide a surface that is dust free and no longer needs to be bladed every week. With these surfaces, there is no need to stripe the pavement (a costs savings) since many times the road geometry has not been improved and to keep people from driving on the weaker edges of these surfaces. Road surfaces of these types have relatively low construction costs, around $20,000 to $25,000 per mile, and can be placed with a county's own forces and equipment that may already be in ownership for maintaining their existing bituminous roads.

Table 16. Costs for bituminous treatment activities and new construction.

Treatment	Cost per Mile	Cycle Time
Seal Coat	$6000	5-7 years
Overlay	$95,000	15-20 years
Crack Sealing	not available	5-7 years
New HMA (9 ton design)	$115,000 (no grading)	
Grading	$175,000 (average)	
Otta Seal	$20,000	10-15 years
Double Chip Seal	$20,000	5-7 years
Oil Gravel	$50,000	5-7 years

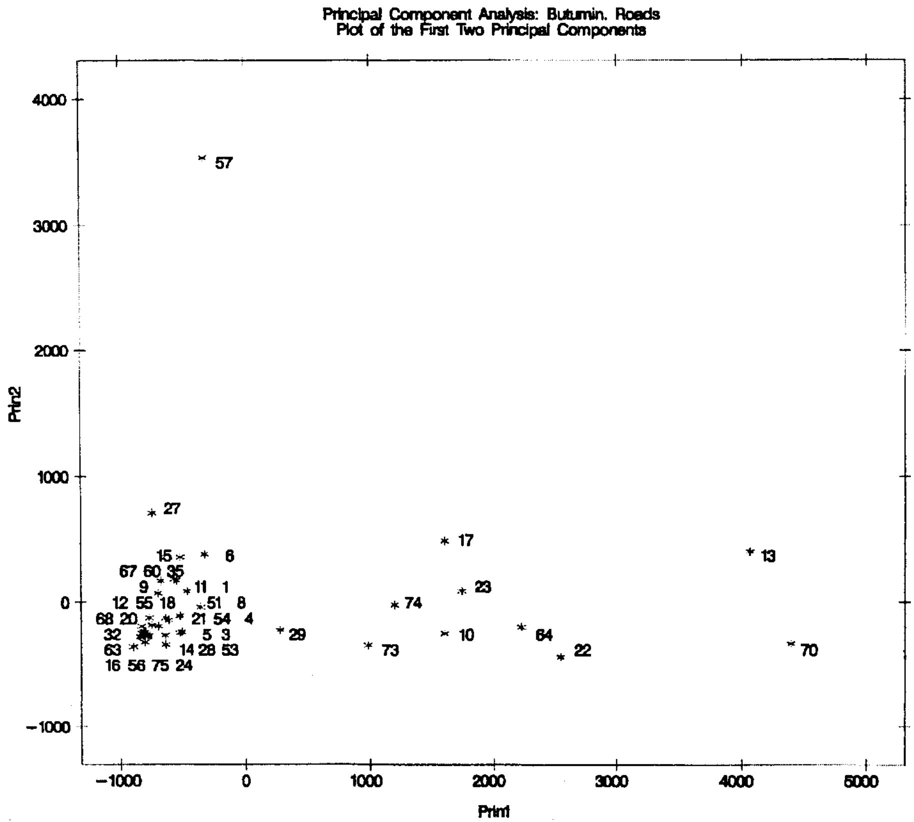
Before choosing to upgrade a road, the officials in charge of maintaining the roads need to implement a road management system if one is not in current use. This will allow them to track the road's history on when the road was constructed and what work has been performed on the road. Also, criteria for upgrading roads should be established, this will allow personnel to go out and rate roads based on various issues and factors in deciding which road to upgrade. These criteria can be used in a rating system, along with the information in the road management system to assist in deciding which roads should be upgraded, or rehabilitated, or when preventative maintenance performed. By doing this, the governing agency will be better able to manage and track how money is being spent on the road network.

Recommendations for future work and research include the placing and evaluation of thin surfaces throughout Minnesota for possible use as intermediate surfacing options to provide additional levels of service between an aggregate road and a traditional bituminous road. This process would include determining what surfaces perform better under various traffic conditions and how much base support is required for the thin surfaces to perform effectively with the different conditions throughout Minnesota. Also, maintenance costs for these surfaces needs to be tracked to help establish a relative cost per mile to maintain such surfaces, much like is currently being done for traditional bituminous and gravel roads. Since there is some concern about the accuracy of the data contained in the reports; counties need to be sure staff are trained to track costs and ensure work activities are charged to the correct road under the correct cost activities. By making sure costs are recorded correctly, counties will be able to better determine the actual money being spent to maintain any given road. Starting a road management system will help in tracking these costs and then allow for comparisons of roads to determine where money is being spent and why.

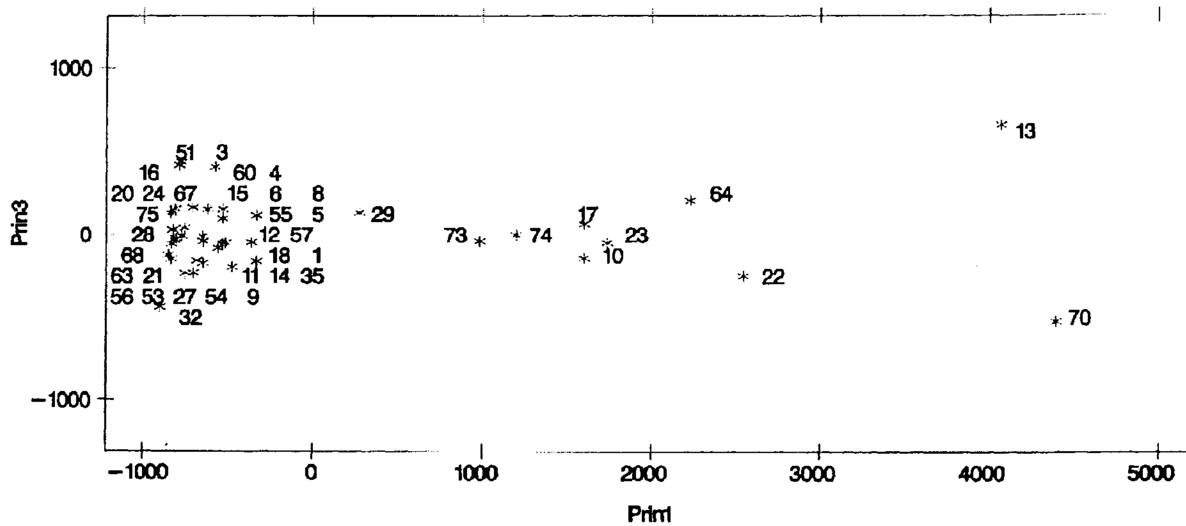
In addition to using road management systems, the governing agencies must decide which factors and reasons are important in selecting which road to upgrade and at what time. Placing these factors into a rating system and then rating the roads every year or two will aid in an objective and thorough decision process. Finally, further work needs to be performed to determine the feasibility of having properties assessed differently based on the road surface they abut. Having houses on bound surfaced roads assessed a higher rate can lead to additional tax revenue for the county that could be reinvested in the road network and help to support future improvement projects.

APPENDIX A: STATISTICAL ANALYSIS RESULTS

Principal Component Analysis Results



Principal Component Analysis: Butumin. Roads
Plot of the First and Third Principal Components



Principal Component Analysis: Sutumin. Roads
10:25 Wednesday, May 21, 20

The PRINCOMP Procedure

Observations	41
Variables	7

Simple Statistics

	F2	F4	F5	F6
Mean	4.551219512	4.86308641	801.556002	42.11116237
StD	4.454879457	17.95525151	1331.985271	98.80156007

Simple Statistics

	F7	F8	F9
Mean	107.2607060	527.8938380	436.1267132
StD	66.7823627	257.7600331	638.540660'

Covariance Matrix

		F2	F4	F5
F2	Length	19.846	-11.092	-655.409
F4	Smoothing Surface	-11.092	322.391	1551.871
F5	Minor Surface Repair	-655.409	1551.871	1774184.763
F6	Cleaning Culverts and Dithches	-9.677	-161.083	20756.444
F7	Brush and Weed Control	29.376	3.806	40666.829
F8	Snow and Ice Removal	-276.332	149.506	169541.718
F9	Traffic Services and Signs	-574.706	-689.010	161242.935

Covariance Matrix

	F6	F7	F8	F9
F2	-9.677	29.376	-276.332	-574.706
F4	-161.083	3.806	149.506	-689.010
F5	20756.444	40666.829	169541.718	161242.935
F6	9761.519	885.179	4285.467	-1947.149
F7	885.179	4459.884	11656.920	3323.742
F8	4285.467	11656.920	66440.235	31506.126
F9	-1947.149	3323.742	31506.126	407744.391

Total Variance 2262953.0285

Principal Component Analysis: Butumin. Roads

10:25 Wednesday, May 21, 20

The PRINCOMP Procedure

Eigenvalues of the Covariance Matrix

	Eigenvalue	Difference	Proportion	Cumulative
1	1811136.25	1421709.55	0.8003	0.8003
2	389426.70	338970.35	0.1721	0.9724
3	50456.35	41102.59	0.0223	0.9947
4	9353.76	7104.15	0.0041	0.9989
5	2249.61	1934.69	0.0010	0.9999
6	314.92	299.49	0.0001	1.0000
7	15.43		0.0000	1.0000

Eigenvectors

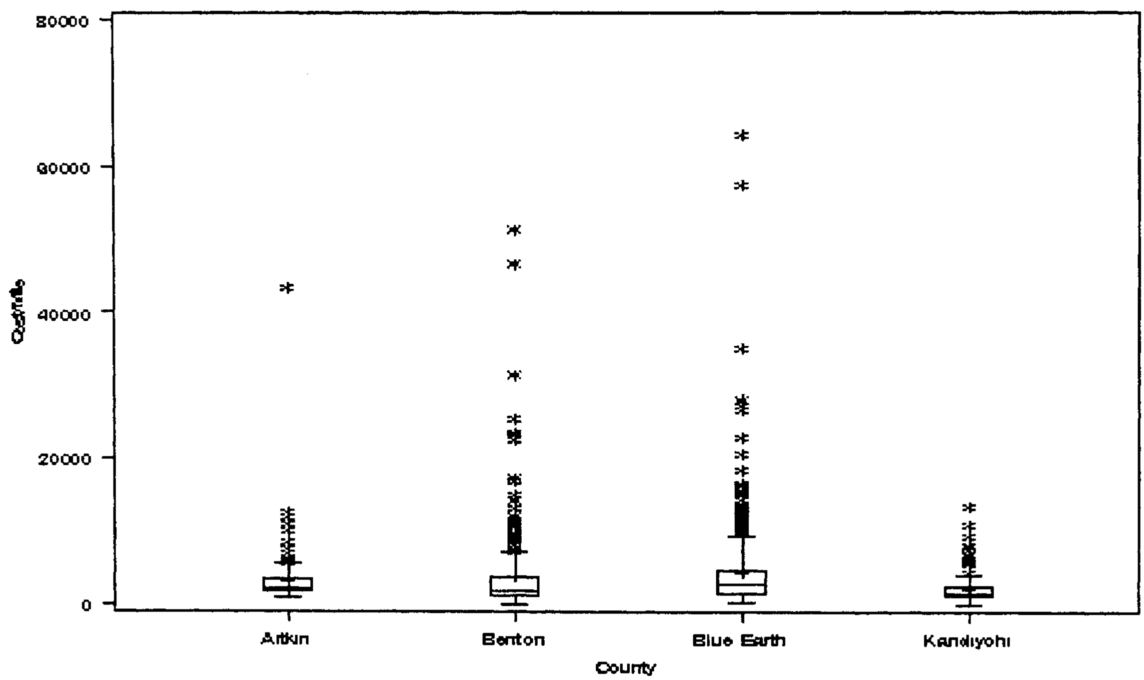
		Prin1	Prin2
F2	Length	-.000409	-.001287
F4	Smoothing Surface	0.000810	-.002216
F5	Minor Surface Repair	0.988084	-.114416
F6	Cleaning Culverts and Dithches	0.011505	-.011242
F7	Brush and Weed Control	0.023093	-.003050
F8	Snow and Ice Removal	0.090299	0.033842
F9	Traffic Services and Signs	0.115763	0.992186

Eigenvectors

	Prin3	Prin4	Prin5	Prin6	Prin7
F2	-.003527	0.000434	0.033493	-.033351	0.998875
F4	0.000352	-.020923	-.019745	0.999004	0.034025
F5	-.096740	-.006954	-.007784	-.001336	0.000128
F6	0.059426	0.997886	-.000666	0.020814	0.000484
F7	0.160666	-.009618	0.985966	0.020287	-.031905
F8	0.979468	-.059087	-.161992	-.005089	0.008830
F9	-.043888	0.012409	0.007611	0.002499	0.000994

$$-.000409 \times (\text{length} - \overline{\text{length}}) + .000810 \times (F4 - \overline{F4}) + \cdots$$

Box Plot of County Data



APPENDIX B: SUMMARY OF AVERAGE COSTS PER MILE

Aitkin County

Traffic Volume Range	County	Smothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Reshaping	Resurfacing	Culverts, Bridges, Guardrails	Washouts	Storm Cleanup
All	mean	43	226	87	178	1048	530	202	17	111	28	3
	std. deviation	161	620	321	177	522	263	719	93	587	292	19
	95% C.I.	24	91	47	26	76	39	105	14	86	43	3
0-49	mean	0	79	0	94	1116	348	0	0	0	0	0
	std. deviation	0	111	0	103	336	153	0	0	0	0	0
	95% C.I.	0	154	0	142	466	213	0	0	0	0	0
50-74	mean	0	283	0	150	1218	469	0	0	0	0	14
	std. deviation	0	618	0	120	333	183	0	0	0	0	44
	95% C.I.	0	383	0	74	206	114	0	0	0	0	27
75-99	mean	0	113	94	163	1076	510	138	0	83	0	0
	std. deviation	0	89	231	197	129	242	275	0	234	0	0
	95% C.I.	0	62	160	136	89	168	190	0	162	0	0
100-124	mean	209	579	5	104	1250	538	135	26	57	0	2
	std. deviation	407	1614	8	58	777	330	247	59	137	0	4
	95% C.I.	266	1055	5	38	508	215	161	38	89	0	2
125-149	mean	0	358	22	175	876	529	119	0	0	0	0
	std. deviation	2	621	42	90	477	191	242	0	0	0	0
	95% C.I.	1	385	26	56	295	119	150	0	0	0	0
150-199	mean	154	59	22	147	703	467	304	87	0	0	0
	std. deviation	328	73	32	112	192	189	984	198	0	0	0
	95% C.I.	186	41	18	63	109	107	557	112	0	0	0
200-249	mean	18	46	140	269	888	472	355	12	13	593	0
	std. deviation	37	30	152	141	299	162	917	31	33	1458	1
	95% C.I.	28	22	113	105	222	120	679	23	25	1080	1
250-299	mean	54	94	66	176	1024	499	160	2	143	11	2
	std. deviation	202	140	145	164	466	234	491	11	556	41	10
	95% C.I.	70	49	50	57	161	81	170	4	193	14	3
300-up	mean	5	165	48	224	881	571	188	0	131	7	1
	std. deviation	15	339	64	174	402	289	512	1	787	28	7
	95% C.I.	4	85	16	44	101	72	128	0	198	7	2

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

Aitkin County

Traffic Volume Range	County	New Culvert Rails/Tiling/ Curb	Cuts & Fills	Seeding & Sodding	Bitum Treatment	Dust Treatments	Mud Jacking & Frost Boils	Mailbox Supports	Total Cost/Mile
All	mean	30	86	0	347	11	6	0	2952
	std. deviation	139	778	4	2249	79	69	0	3573
	95% C.I.	20	114	1	329	12	10	0	523
0-49	mean	0	0	0	0	0	0	0	1635
	std. deviation	0	0	0	0	0	0	0	703
	95% C.I.	0	0	0	0	0	0	0	974
50-74	mean	7	0	0	0	0	0	0	2139
	std. deviation	21	0	0	0	0	0	0	787
	95% C.I.	13	0	0	0	0	0	0	487
75-99	mean	58	0	0	0	0	0	0	2235
	std. deviation	164	0	0	0	0	0	0	532
	95% C.I.	114	0	0	0	0	0	0	369
100-124	mean	47	0	0	72	9	0	0	3032
	std. deviation	78	0	0	157	27	0	0	2226
	95% C.I.	51	0	0	103	18	0	0	1455
125-149	mean	26	0	0	16	0	0	0	2122
	std. deviation	77	0	0	45	0	0	0	1156
	95% C.I.	48	0	0	28	0	0	0	716
150-199	mean	16	0	0	0	0	9	0	1968
	std. deviation	31	0	0	1	1	31	0	1299
	95% C.I.	17	0	0	0	1	17	0	735
200-249	mean	37	261	0	605	0	0	0	3708
	std. deviation	65	692	0	1312	0	0	0	1608
	95% C.I.	48	512	0	972	0	0	0	1191
250-299	mean	15	66	2	188	14	29	0	2545
	std. deviation	44	376	10	894	65	162	0	1323
	95% C.I.	15	130	3	310	23	56	0	458
300-up	mean	13	187	0	358	0	0	0	2779
	std. deviation	39	1284	3	1222	0	0	0	2170
	95% C.I.	10	322	1	307	0	0	0	544

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

Benton County

Traffic Volume Range	County	Smothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Reshaping	Resurfacing	Culverts, Bridges, Guardrails	Washouts	Storm Cleanup
All	mean	52	246	43	169	572	406	382	61	46	8	4
	std. deviation	264	316	102	184	477	333	906	302	190	34	24
	95% C.I.	30	36	12	21	55	38	104	35	22	4	3
0-49	mean	38	415	44	89	1183	621	7	0	0	0	0
	std. deviation	146	669	76	139	1268	458	20	0	0	0	0
	95% C.I.	74	339	39	70	642	232	10	0	0	0	0
50-74	mean	49	131	13	424	298	271	248	190	161	19	2
	std. deviation	154	235	22	710	240	267	725	596	239	51	6
	95% C.I.	95	146	13	440	148	165	449	370	148	32	4
75-99	mean	173	146	61	135	523	322	411	166	51	14	0
	std. deviation	544	127	184	131	267	209	783	448	134	55	2
	95% C.I.	238	56	81	57	117	92	343	196	59	24	1
100-124	mean	13	108	6	152	503	352	784	250	0	5	6
	std. deviation	21	47	9	148	187	259	2476	542	0	16	17
	95% C.I.	13	29	5	92	116	161	1535	336	0	10	10
125-149	mean	57	289	10	165	430	338	533	180	36	16	12
	std. deviation	94	462	14	162	337	250	986	600	71	39	43
	95% C.I.	41	203	6	71	148	110	432	263	31	17	19
150-199	mean	15	217	22	148	624	568	585	79	7	4	5
	std. deviation	23	274	25	85	422	557	1424	274	24	11	17
	95% C.I.	12	139	13	43	214	282	721	139	12	5	8
200-249	mean	17	211	42	163	499	289	288	6	30	6	1
	std. deviation	91	208	154	114	344	146	653	14	85	19	3
	95% C.I.	25	58	43	32	95	40	181	4	24	5	1
250-299	mean	11	299	40	170	478	336	553	17	35	1	9
	std. deviation	24	207	62	121	219	169	1027	38	72	4	29
	95% C.I.	10	91	27	53	96	74	450	17	31	2	13
300-up	mean	17	302	62	184	641	455	367	16	38	9	3
	std. deviation	66	319	90	109	402	355	721	53	154	42	11
	95% C.I.	12	60	17	20	75	66	135	10	29	8	2

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

Benton County

Traffic Volume Range	County	New Culvert Rails/Tiling/ Curb	Cuts & Fills	Seeding & Sodding	Bitum Treatment	Dust Treatments	Mud Jacking & Frost Boils	Mailbox Supports	Total Cost/Mile
All	mean	68	34	3	1526	1	27	7	3656
	std. deviation	281	165	16	4725	10	187	36	5725
	95% C.I.	32	19	2	545	1	22	4	660
0-49	mean	316	0	0	5	0	0	0	2716
	std. deviation	858	0	0	20	0	0	0	1858
	95% C.I.	434	0	0	10	0	0	0	940
50-74	mean	356	19	6	1829	0	0	0	4013
	std. deviation	725	59	18	5785	0	0	0	6930
	95% C.I.	449	37	11	3586	0	0	0	4295
75-99	mean	72	64	15	2546	0	60	2	4763
	std. deviation	169	271	45	4995	0	218	7	6289
	95% C.I.	74	119	20	2189	0	96	3	2756
100-124	mean	7	5	0	4266	0	0	8	6464
	std. deviation	22	15	0	13014	0	0	25	15772
	95% C.I.	14	10	0	8066	0	0	15	9775
125-149	mean	58	18	1	2867	9	17	6	5043
	std. deviation	111	42	2	5291	35	77	14	6402
	95% C.I.	49	18	1	2319	15	34	6	2806
150-199	mean	35	0	0	3732	0	10	0	6052
	std. deviation	54	0	0	7867	0	37	1	9327
	95% C.I.	27	0	0	3981	0	19	1	4720
200-249	mean	19	2	2	976	0	6	5	2562
	std. deviation	39	12	8	2066	0	25	16	2712
	95% C.I.	11	3	2	573	0	7	4	752
250-299	mean	23	0	0	2596	0	6	3	4577
	std. deviation	45	0	1	5056	0	22	9	5744
	95% C.I.	20	0	0	2216	0	9	4	2517
300-up	mean	43	72	4	697	1	52	14	2977
	std. deviation	105	235	16	1820	5	285	56	2396
	95% C.I.	20	44	3	340	1	53	11	448

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

Blue Earth County

Traffic Volume Range	County	Smothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Reshaping	Resurfacing	Culverts, Bridges, Guardrails	Washouts	Storm Cleanup
All	mean	135	728	71	325	843	303	79	486	154	112	0
	std. deviation	225	1801	287	414	854	407	298	892	1093	1484	0
	95% C.I.	21	171	27	39	81	39	28	85	104	141	0
0-49	mean	372	457	64	260	491	130	228	485	40	3	0
	std. deviation	174	864	89	101	295	142	516	589	68	10	0
	95% C.I.	113	564	58	66	193	93	337	385	44	7	0
50-74	mean	353	14	32	185	621	67	49	638	102	30	0
	std. deviation	48	13	52	78	418	44	65	436	207	77	0
	95% C.I.	33	9	36	54	290	30	45	302	144	53	0
75-99	mean	267	491	89	245	694	144	64	751	50	10	0
	std. deviation	232	944	178	122	336	167	119	819	124	36	0
	95% C.I.	110	449	85	58	160	79	57	389	59	17	0
100-124	mean	122	485	24	217	580	148	25	446	18	4	0
	std. deviation	168	1023	40	76	316	122	35	791	27	9	0
	95% C.I.	88	536	21	40	165	64	18	414	14	4	0
125-149	mean	320	247	18	243	714	114	42	431	50	16	0
	std. deviation	279	489	33	142	474	117	66	524	103	49	0
	95% C.I.	102	178	12	52	172	43	24	191	38	18	0
150-199	mean	139	549	39	300	684	192	25	393	22	5	0
	std. deviation	196	1245	71	250	370	169	37	769	35	17	0
	95% C.I.	56	352	20	71	105	48	10	217	10	5	0
200-249	mean	346	556	14	237	571	192	21	580	26	3	0
	std. deviation	454	1193	26	167	281	160	23	695	44	9	0
	95% C.I.	204	536	12	75	127	72	10	313	20	4	0
250-299	mean	193	419	43	250	583	204	45	432	13	11	0
	std. deviation	267	738	50	123	216	143	69	661	24	42	0
	95% C.I.	97	269	18	45	79	52	25	240	9	15	0
300-up	mean	71	832	74	295	721	345	67	540	162	225	0
	std. deviation	161	1394	257	273	459	345	118	1079	1231	2190	0
	95% C.I.	23	199	37	39	66	49	17	154	176	313	0

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

Blue Earth County

Traffic Volume Range	County	New Culvert Rails/Tiling/ Curb	Cuts & Fills	Seeding & Sodding	Bitum Treatment	Dust Treatments	Mud Jacking & Frost Boils	Mailbox Supports	Total Cost/Mile
All	mean	167	126	20	804	2	0	0	4356
	std. deviation	786	845	88	2389	14	0	0	5959
	95% C.I.	75	80	8	227	1	0	0	566
0-49	mean	47	157	9	10	0	0	0	2753
	std. deviation	64	456	19	18	0	0	0	1841
	95% C.I.	42	298	12	12	0	0	0	1203
50-74	mean	59	3	4	61	1	0	0	2219
	std. deviation	75	6	6	159	3	0	0	863
	95% C.I.	52	4	4	110	2	0	0	598
75-99	mean	42	11	17	690	4	0	0	3568
	std. deviation	74	31	53	1954	13	0	0	3237
	95% C.I.	35	15	25	929	6	0	0	1539
100-124	mean	29	6	3	362	0	0	0	2469
	std. deviation	66	13	9	923	0	0	0	1970
	95% C.I.	35	7	5	483	0	0	0	1032
125-149	mean	372	397	34	420	4	0	0	3422
	std. deviation	1122	1793	165	1932	10	0	0	3074
	95% C.I.	408	653	60	703	4	0	0	1119
150-199	mean	51	22	18	1040	1	0	0	3481
	std. deviation	78	90	73	3143	3	0	0	4648
	95% C.I.	22	25	21	889	1	0	0	1315
200-249	mean	59	5	2	471	8	0	0	3090
	std. deviation	82	11	9	1480	24	0	0	3121
	95% C.I.	37	5	4	666	11	0	0	1403
250-299	mean	87	4	1	972	2	0	0	3258
	std. deviation	197	12	2	2480	10	0	0	3371
	95% C.I.	72	4	1	903	4	0	0	1227
300-up	mean	148	121	17	830	3	0	0	4452
	std. deviation	845	733	52	2054	17	0	0	5820
	95% C.I.	121	105	7	294	2	0	0	832

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

Kandiyohi County

Traffic Volume Range	County	Smothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Reshaping	Resurfacing	Culverts, Bridges, Guardrails	Washouts	Storm Cleanup
All	mean	121	166	118	122	684	234	77	124	28	16	0
	std. deviation	305	416	663	183	580	195	173	394	332	59	0
	95% C.I.	34	47	74	20	65	22	19	44	37	7	0
0-49	mean	341	8	6	178	506	99	10	293	107	0	0
	std. deviation	443	25	12	285	373	22	22	431	338	0	0
	95% C.I.	274	16	8	176	231	14	14	267	209	0	0
50-74	mean	683	17	86	110	370	140	9	1799	6	22	0
	std. deviation	127	25	82	102	275	10	4	232	10	28	0
	95% C.I.	144	28	93	115	311	11	4	262	11	31	0
75-99	mean	57	166	116	239	2135	285	63	0	0	10	0
	std. deviation	105	166	127	136	916	200	92	0	0	22	0
	95% C.I.	92	146	111	119	803	175	80	0	0	19	0
100-124	mean	308	240	17	75	460	154	6	546	0	4	0
	std. deviation	452	499	17	24	343	130	9	827	0	8	0
	95% C.I.	229	253	8	12	174	66	5	419	0	4	0
150-199	mean	278	354	54	197	766	224	65	174	162	17	0
	std. deviation	551	774	75	359	487	184	167	432	956	31	0
	95% C.I.	182	256	25	119	161	61	55	143	317	10	0
200-249	mean	274	45	42	67	356	162	14	403	0	3	0
	std. deviation	493	120	60	63	292	126	25	792	0	6	0
	95% C.I.	216	52	26	28	128	55	11	347	0	3	0
250-299	mean	2	118	43	94	491	271	31	7	15	10	0
	std. deviation	7	175	34	60	239	144	44	21	38	10	0
	95% C.I.	5	108	21	37	148	89	27	13	24	6	0
300-up	mean	58	153	144	126	728	283	115	37	10	22	0
	std. deviation	145	260	822	153	544	212	208	112	61	76	0
	95% C.I.	22	39	123	23	81	32	31	17	9	11	0

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

Kandiyohi County

Traffic Volume Range	County	New Culvert Rails/Tiling/ Curb	Cuts & Fills	Seeding & Sodding	Bitum Treatment	Dust Treatments	Mud Jacking & Frost Boils	Mailbox Supports	Total Cost/Mile
All	mean	17	59	1	147	1	0	0	1917
	std. deviation	78	563	7	769	5	0	0	1600
	95% C.I.	9	63	1	86	1	0	0	179
0-49	mean	22	0	0	0	0	0	0	1569
	std. deviation	70	0	0	0	0	0	0	1257
	95% C.I.	44	0	0	0	0	0	0	779
50-74	mean	0	0	0	0	0	0	0	3241
	std. deviation	0	0	0	0	0	0	0	491
	95% C.I.	0	0	0	0	0	0	0	556
75-99	mean	0	0	0	0	0	0	0	3070
	std. deviation	0	0	0	0	0	0	0	831
	95% C.I.	0	0	0	0	0	0	0	728
100-124	mean	19	0	0	0	0	0	0	1830
	std. deviation	46	0	0	0	0	0	0	1041
	95% C.I.	23	0	0	0	0	0	0	527
150-199	mean	34	0	0	148	1	0	0	2472
	std. deviation	121	0	0	873	3	0	0	1697
	95% C.I.	40	0	0	289	1	0	0	562
200-249	mean	14	3	3	205	0	0	0	1592
	std. deviation	47	13	10	622	1	0	0	1456
	95% C.I.	21	6	5	273	1	0	0	638
250-299	mean	99	531	2	33	0	0	0	1746
	std. deviation	300	1680	4	104	0	0	0	1803
	95% C.I.	186	1041	3	64	0	0	0	1118
300-up	mean	13	74	2	205	1	0	0	1971
	std. deviation	45	631	9	917	7	0	0	1641
	95% C.I.	7	94	1	137	1	0	0	245

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

Meeker

Traffic Volume Range	County	Smothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Reshaping	Resurfacing	Culverts, Bridges, Guardrails	Washouts	Storm Cleanup
All	mean	12	158	93	48	39	110	1	33	42	0	0
	std. deviation	58	456	250	44	121	141	6	113	150	0	0
	95% C.I.	9	72	39	7	19	22	1	18	24	0	0
100-124	mean	85	75	1	15	100	163	0	7	0	0	0
	std. deviation	148	131	1	14	114	11	0	12	0	0	0
	95% C.I.	168	148	2	16	129	12	0	14	0	0	0
150-199	mean	1	156	116	23	31	126	0	0	0	0	0
	std. deviation	2	441	126	29	63	128	0	1	0	0	0
	95% C.I.	1	306	88	20	44	88	0	0	0	0	0
200-249	mean	3	251	111	42	33	68	3	80	24	0	0
	std. deviation	9	802	251	48	97	81	15	204	102	0	0
	95% C.I.	4	314	98	19	38	32	6	80	40	0	0
250-299	mean	1	264	91	58	17	94	0	18	133	0	0
	std. deviation	2	525	132	34	31	80	0	32	279	0	0
	95% C.I.	1	275	69	18	16	42	0	17	146	0	0
300-up	mean	15	122	85	54	44	115	0	30	42	0	0
	std. deviation	69	339	270	44	143	143	1	97	148	0	0
	95% C.I.	14	68	54	9	29	29	0	19	30	0	0

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

Meeker

Traffic Volume Range	County	New Culvert Rails/Tiling/ Curb	Cuts & Fills	Seeding & Sodding	Bitum Treatment	Dust Treatments	Mud Jacking & Frost Boils	Mailbox Supports	Total Cost/Mile
All	mean	31	37	21	11	0	0	0	634
	std. deviation	246	249	160	124	0	0	0	855
	95% C.I.	39	39	25	20	0	0	0	135
100-124	mean	0	7	0	0	0	0	0	453
	std. deviation	0	12	0	0	0	0	0	280
	95% C.I.	0	14	0	0	0	0	0	317
150-199	mean	0	0	0	0	0	0	0	453
	std. deviation	0	0	0	0	0	0	0	459
	95% C.I.	0	0	0	0	0	0	0	318
200-249	mean	4	10	17	0	0	0	0	648
	std. deviation	13	22	83	2	0	0	0	854
	95% C.I.	5	9	33	1	0	0	0	335
250-299	mean	0	5	1	0	0	0	0	682
	std. deviation	0	11	2	0	0	0	0	575
	95% C.I.	0	6	1	0	0	0	0	301
300-up	mean	48	57	29	17	0	0	0	660
	std. deviation	314	317	200	159	0	0	0	959
	95% C.I.	63	64	40	32	0	0	0	193

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

All Four Counties (Aitkin, Benton, Blue Earth, and Kandiyohi)

Traffic Volume Range	County	Smothing Surface	Minor Surface Repair	Cleaning Culverts & Ditches	Brush & Weed Control	Snow & Ice Removal	Traffic Services	Reshaping	Resurfacing	Culverts, Bridges, Guardrails	Washouts	Storm Cleanup
All	mean	97	389	79	212	767	344	171	218	89	49	1
	std. deviation	253	1144	401	296	678	338	577	614	710	881	14
	95% C.I.	14	65	23	17	38	19	33	35	40	50	1
0-49	mean	203	294	36	157	818	338	63	202	40	1	0
	std. deviation	304	624	69	190	906	389	266	412	180	5	0
	95% C.I.	99	204	23	62	296	127	87	135	59	2	0
50-74	mean	173	139	21	243	685	269	93	400	79	16	5
	std. deviation	242	379	43	417	502	240	413	658	179	48	25
	95% C.I.	85	134	15	147	177	85	145	232	63	17	9
75-99	mean	166	260	81	187	831	288	215	322	51	10	0
	std. deviation	377	574	181	145	603	231	530	631	142	41	1
	95% C.I.	105	159	50	40	167	64	147	175	39	11	0
100-124	mean	173	348	15	138	652	265	198	358	16	3	2
	std. deviation	331	916	25	100	508	254	1131	686	62	10	8
	95% C.I.	94	259	7	28	144	72	320	194	18	3	2
125-149	mean	177	280	16	205	645	260	221	273	37	13	4
	std. deviation	247	497	30	145	456	241	617	528	84	41	25
	95% C.I.	63	127	8	37	116	61	158	135	22	10	6
150-199	mean	168	388	39	230	704	283	144	247	62	8	1
	std. deviation	360	945	65	271	402	293	637	587	539	22	6
	95% C.I.	67	177	12	51	75	55	119	110	101	4	1
200-249	mean	136	233	44	165	512	256	183	203	22	48	1
	std. deviation	337	571	124	134	339	165	541	526	66	398	2
	95% C.I.	67	114	25	27	68	33	108	105	13	80	0
250-299	mean	83	245	50	189	705	344	196	143	64	8	3
	std. deviation	206	457	95	141	403	221	588	419	334	34	15
	95% C.I.	42	94	20	29	83	45	121	86	69	7	3
300-up	mean	48	424	91	209	725	373	158	205	83	89	1
	std. deviation	132	911	496	211	474	317	410	688	782	1301	6
	95% C.I.	11	77	42	18	40	27	35	58	66	111	0

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

All Four Counties (Aitkin, Benton, Blue Earth, and Kandiyohi)

Traffic Volume Range	County	New Culvert Rails/Tiling/ Curb	Cuts & Fills	Seeding & Sodding	Bitum Treatment	Dust Treatments	Mud Jacking & Frost Boils	Mailbox Supports	Total Cost/Mile
All	mean	83	80	8	742	3	8	2	3341
	std. deviation	491	654	53	2931	32	97	18	4874
	95% C.I.	28	37	3	166	2	5	1	276
0-49	mean	150	39	2	5	0	0	0	2347
	std. deviation	563	229	10	16	0	0	0	1697
	95% C.I.	184	75	3	5	0	0	0	554
50-74	mean	132	7	3	606	0	0	0	2871
	std. deviation	429	34	11	3284	2	0	0	3940
	95% C.I.	151	12	4	1156	1	0	0	1387
75-99	mean	52	29	12	1253	1	24	1	3783
	std. deviation	131	172	42	3483	8	139	4	4439
	95% C.I.	36	48	12	965	2	39	1	1230
100-124	mean	25	3	1	1008	2	0	2	3207
	std. deviation	56	10	5	5962	12	0	11	7274
	95% C.I.	16	3	1	1687	3	0	3	2058
125-149	mean	207	201	17	1181	5	6	2	3751
	std. deviation	800	1261	116	3532	22	45	9	4391
	95% C.I.	204	322	30	901	5	11	2	1121
150-199	mean	40	10	8	1010	1	2	0	3345
	std. deviation	88	60	49	3717	3	17	0	4799
	95% C.I.	17	11	9	695	1	3	0	897
200-249	mean	27	22	2	689	2	3	2	2548
	std. deviation	55	187	8	1705	11	18	12	2564
	95% C.I.	11	37	2	341	2	4	2	513
250-299	mean	49	83	1	950	6	11	1	3131
	std. deviation	153	597	6	2914	39	96	4	3498
	95% C.I.	31	123	1	599	8	20	1	719
300-up	mean	67	103	7	544	2	11	3	3143
	std. deviation	507	718	33	1635	11	131	26	3940
	95% C.I.	43	61	3	139	1	11	2	335

The 95% Confidence Intervals (95% C.I.) are found by adding and subtracting those values from the mean for each activity and traffic volume.

APPENDIX C: DATA SETS USED IN ANALYSIS

The data sets used for analysis and the five number summaries of the data are found in the CD-ROM. To access this information a Windows compatible machine is needed with at least Microsoft Excel 97 or other spreadsheet program capable of reading Microsoft Excel 97 files.

APPENDIX D: SAMPLE PRIORITY RATING WORKSHEET

Aitkin Co.

9/12/00

Priority Rating Worksheet

Major Reconstruction Program

Road Number	Segment Description	Length	Projected ADT (20 points)	Number of Seasonal and FT Residences (20 points)	Number of Seasonal and FT Residences Per Mile	Functional Classification (10 points)	Sight Distance Safety Rating (10 points)	Part of Larger Improved Route (10 points)	Percentage of Private land Adjacent to Segment (10 points)	Priority Rating (80 points)
29	CSAH 3 to 2.3 miles North	2.3	225	17	7.39	7	84.44	0	100	48.15
54	Between blacktop	0.5	360	2	4.00	4	0	10	100	48.05
62	TH 210 to 2 miles North	2	405	16	8.00	4	0	0	90	45.55
32	CSAH 6 to Carlton County Line	6 3	180	32	5.08	7	15.38	10	90	44.39
23	TH 18 to Beginning of Pavemenx	4 5	210	18	4.00	10	63.47	0	95	42.49
10	Between blacktop	6.8	165	4	0.59	10	59.94	10	70	42 06
10	TH 169 to TH 232	7.12	300	17	2.39	10	38.91	0	85	41 95
25	CSAH 23 to Kanabec County Line	3.3	90	10	3.03	7	35.01	10	100	39 70
62	2 miles N of TH 210 to CR 71	2	405	6	3.00	4	0	0	100	38.71
5	TH 47 to CR 56	8	210	28	3.50	10	32.24	0	95	38.58
2	CSAH 26 to Pine County Line	4 4	165	10	2.27	10	14.88	10	50	38.20
71		1	315	5	5.00	4	0	0	100	37.40
53	CSAH 4 to CSAH 5	3.08	203	21	6.82	4	17.87	0	100	36.51
88		1.02	120	13	12.75	0	0	0	75	33.42
5	CR 56 to TH 210	3.6	210	3	0.83	10	44.6	0	65	32.64
13	CSAH 16 to Carlton County Line	5.6	120	5	0.89	7	22.01	10	60	32.53
21	CSAH 1 to TH 169	6.9	83	10	1.45	10	30.59	0	95	28.93
85		0.5	40	4	8.00	0	41.84	0	100	28.71
61	TH 18 to CSAH 23	7	90	22	3.14	7	31.44	0	90	28.52
87		0.6	40	3	5.00	4	43.98	0	100	28.22
72		1.2	150	3	2.50	4	28.43	0	100	28.17
36	CR 65 to 1.5 miles N of CSAH 14	5.2	135	12	2.31	7	46.45	0	60	27.93
57	TH 65 to 5 miles east	5	120	16	3.20	4	30.48	0	95	27.49
30	TH 65 to CSAH 16	7	128	16	2.29	4	39.77	0	95	27.38
63		2.89	68	6	2.23	4	81.38	0	100	26.99
19	Cass County Line to CSAH 20	4.8	98	11	2.29	10	44.35	0	40	26.87
57	TH 27 to 4 miles North	4	120	8	2.00	4	42.08	0	95	26.77
36	TH 65 to CR 65	4.1	135	5	1.22	7	61.57	0	50	26.74
27	CSAH 13 to TH 27	6.6	68	20	3.03	7	26.10	0	90	26 73
60		5.08	113	19	3.74	4	11.37	0	100	26.58
19	CSAH 20 to CSAH 29	2	98	5	2.50	10	26.15	0	50	26.38
29	2.3 miles N of CSAH 3 to CR 68	3 3	225	5	1.52	7	6.34	0	45	25.62
28	CSAH 38 to CR 59	5	83	9	1.80	7	14.64	0	100	25.39
61	TH 65 to TH 18	4.23	60	15	3.55	4	33.44	0	95	25.37
51	TH 18 to CSAH 28	4 77	105	17	3.56	4	14.88	0	85	24.76
59		4 28	135	9	2.10	4	12.22	0	95	24.69
26	CR 59 to TH 65	6	83	18	3.00	7	8.72	0	75	24 18
18	CSAH 5 to CSAH 10	6.2	113	4	0.65	7	10.64	0	95	24.16
29	CR 68 to CSAH 7	6 3	225	7	1.11	7	12.92	0	30	24.15
62	CR 71 to TH 232	4	90	11	2.75	4	12.51	0	100	24.01
1	3.6 miles N of CSAH 22 to CSAH 3	7.4	135	12	1.62	7	7.81	0	70	23.99
74		2	75	4	2.00	4	27.52	0	100	23.59
65		8.96	90	14	1.56	4	76.91	0	50	23.59
29	CSAH 7 to CR 67	4 8	83	10	2.08	7	20.75	0	70	23.44
84		1.4	53	6	4.29	0	37.69	0	100	23.11
75	TH 27 to CSAH 34	6.9	90	7	1.01	7	30.38	0	70	23.07
86		0.6	40	2	3.33	0	56.86	0	100	22.89
20	Cass County Line to CSAH 19	6.9	45	17	2.46	7	26.64	0	70	22.75
5	TH 232 to CSAH 18	7.81	120	15	1.92	7	4.37	0	60	22.38
55		1.47	40	5	3.40	0	44.87	0	100	21.80
64	CSAH 32 to 5 miles North	5	173	6	1.20	4	21.56	0	50	21.58
67		5.17	60	9	1.74	4	36.51	0	80	21.34
34	CSAH 2 to CR 75	6.3	45	13	2.06	7	15.81	0	70	21 04
54	End of Blacktop to TH 210	4.77	75	6	1.26	4	16.59	0	95	20.84
58		2 67	30	8	3.00	4	23.51	0	80	20.53
73		5.1	120	10	1.96	4	7.76	0	65	20.28
54	CR 54 to TH 210	1.75	75	2	1.14	4	22.62	0	85	20.26
80		1.7	83	1	0.59	4	12.31	0	100	20.25
26	TH 65 to CSAH 2	9.1	75	10	1.10	7	27.09	0	50	20.14
64	5 miles N of CSAH 32 to CSAH 14	4.49	60	8	1.34	4	39.31	0	70	19.99
56	Rice River to CSAH 5	3.9	30	3	0.77	4	46.66	0	80	19.35
18	TH 169 to CSAH 5	6	113	1	0.17	7	6.6	0	50	18.50
29	CR 67 to TH 200	2	83	2	1.00	7	10.46	0	40	17.71
89		1	40	1	1.00	4	0	0	100	17.54
35	TH 65 to Itasca County Line	0.4	68	0	0.00	4	0	0	100	17.36
68	CSAH 29 to dead end west	2	60	4	2.00	0	31.38	0	80	17.24
56	TH 210 to Rice River	4.5	90	0	0.00	4	8.8	0	65	15.82
68	Th 169 to dead end east	1.2	60	2	1.67	0	10.99	0	80	14.68
68	CSAH 29 to TH 169	3.2	60	2	0.83	4	14.78	0	40	13.42

9   2001-2006 Road Improvement Program.xls

Sample priority rating worksheet is courtesy of Aitkin County.

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