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Final Report

Economics of Upgrading an Aggregate Road

Research

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16. Abstract (Limit: 200 words)

This report describes a research project that provides Minnesota counties, and townships with information and procedures to make informed decisions on when it may be advantageous to upgrade and pave gravel roads. It also provides resources to assist county and township governments in explaining to the public why certain maintenance or construction techniques and policy decisions are made.

The research involved three major efforts. The first is a historical cost analysis based on the spending history for low-volume roads found in the annual reports of selected Minnesota counties. The effects of traffic volume and type of road surface on cost was included in the analysis. The second was the development of a method for estimating the cost of maintaining gravel roads, which is useful when requirements for labor, equipment and materials can be predicted. The third is the development of an economic analysis example that can serve as a starting point for analyses to aid in making specific decisions. Additional information was gleaned from numerous interviews with local road officials. Maintenance and upgrading activities considered included: maintenance grading, re-graveling, dust control/stabilization, reconstruction/re-grading, paving, and others.

As part of this report, an analysis is developed that compares the cost of maintaining a gravel road with the cost of upgrading to a paved surface. This analysis can be modified to address local conditions. Such an analysis may be used as a tool to assist in making decisions about upgrading a gravel road to a paved surface.

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Economics of Upgrading an Aggregate Road

Final Report

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2005-09 Executive Summary

This report describes a research project that provides Minnesota counties, and townships with information and procedures to make informed decisions on when it may be advantageous to upgrade and pave gravel roads. It also provides resources to assist county and township governments in explaining to the public why certain maintenance or construction techniques and policy decisions are made.

The research involved three major efforts. The first is a historical cost analysis based on the spending history for low-volume roads found in the annual reports of selected Minnesota counties. The effects of traffic volume and type of road surface on cost are included in the analysis. The second was the development of a method for estimating the cost of maintaining gravel roads, which is useful when requirements for labor, equipment and materials can be predicted. The third is the development of an economic analysis example that can serve as a starting point for analyses to aid in making specific decisions. Additional information was gleaned from numerous interviews with local road officials. Maintenance and upgrading activities considered included: maintenance grading, re-graveling, dust control/stabilization, reconstruction/re-grading, paving, and others.

As part of this report, an analysis is developed that compares the cost of maintaining a gravel road with the cost of upgrading to a paved surface. This analysis can be modified to address local conditions. Such an analysis may be used as a tool to assist in making decisions about upgrading a gravel road to a paved surface.

Considerable effort has been invested in this study to identify major issues, locate an excellent source of cost data, and learn how manipulate it to analyze the data. Additional effort could be justified to identify high-volume gravel roads, interview local officials to ascertain that costs are being properly recorded, and analyze a larger group that could serve as a point of comparison to bituminous roads with similar traffic volumes.

In this effort, central tendency was documented by calculating mean values and dispersion was documented by calculating variance. Further investigation has shown that it is likely that most of the data is not normally distributed. Therefore, the results of the analysis would be more useful if central tendencies were documented by calculating the median and dispersion was documented by giving high and low percentiles.

Acknowledgements

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The research project advisory committee includes the following members:

David Fricke, Minnesota Association of Townships
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A special thanks is also given to John Welle of Aitkin County, Robert Kozel of Benton County, Alan Forsberg of Blue Earth County, Gary Danielson of Kandiyohi County, Ronald Mortensen of Meeker County, Mike Sheehan of Olmsted County, Kaye Bieniek of Olmsted County, Kevin Harms of Olmsted County and Jeff Blue of Waseca County.

INTRODUCTION

Townships, cities, counties, private companies and individuals are always faced with the decision on the best approach to maintain a gravel road and at what point to upgrade it. Previously there has been limited information available for decision-making on the costs, standards and performance of different options. This research examines the costs to construct and maintain various types of road surfaces found in Minnesota counties. It identifies possible threshold values to go from gravel to hot mix asphalt (HMA) paving. This report provides resources to assist county and township governments in explaining to the public why certain maintenance or construction techniques and policy decisions are made. A similar evaluation of the costs recorded by cities would give Minnesota cities the same information and assistance in making decisions to upgrade and pave a gravel road.

The term “gravel” is used throughout this report and is used to indicate an aggregate road surfaced with either natural gravel or crushed rock. The cost data that was evaluated used the term “bituminous” which covered all asphalt surfaces. The evaluation in this report assumes that an upgrade to a gravel road would be to Hot Mix Asphalt (HMA). As a result, these terms are used in this report. In practice, other surfacing could be used and cost calculations could be adjusted accordingly. Also, a roadway may go through an evolution that includes starting as dirt (unsurfaced), then gravel is added, next additional base rock is added and a seal coat is applied and finally the roadway is paved with HMA. This research identifies the methods and costs to maintain and upgrade a gravel road. The research effort is based on the spending history for low-volume roads found in the annual reports of selected Minnesota counties as well as cost estimates and interviews with local officials. A further effort was made to develop cost estimating methods that may be used when requirements for labor, equipment and materials may be predicted. An example is given on how cost could be evaluated on a life cycle basis with values given in per mile units. The proportion of paved roads at various traffic volumes for four representative counties and this analysis provides guidance about when serious consideration should be given to upgrading a gravel road. The counties were considered by the researchers to be representative in terms of traffic, geography and potential for development that would generate traffic.

OBJECTIVE

This research objective is to identify the methods and costs of maintaining and upgrading a gravel road. The costs are from the county maintenance operations where they use their own forces for gravel road maintenance activities. The upgrading activities, however, were usually contracted out.

The research goal was to provide local officials with methods to determine at what point it is desirable to upgrade a gravel road. As part of this effort, costs were evaluated to determine if the investment in upgrading the road is justified by the cost savings in annual maintenance expenditures for a gravel road. The research effort is based on the spending history for low-volume roads found in the annual reports of selected counties to the Minnesota State Aid Office as well as cost estimates based on information obtained from interviews.

The research involved three major efforts. The first is a historical cost analysis based on the spending history for low-volume roads found in the annual reports of selected Minnesota counties. The effects of traffic volume and type of road surface on cost was included in the analysis. The second—the development of a method for estimating the cost of maintaining gravel roads—is useful when requirements for labor, equipment and materials can be predicted. The third is the development of economic analysis example that can serve as a starting point for analyses to aid in making specific decisions. Additional information was gleaned from numerous interviews with local road officials. Maintenance and upgrading activities considered included: maintenance grading, re-graveling, dust control/stabilization, reconstruction/re-grading, paving, and others.

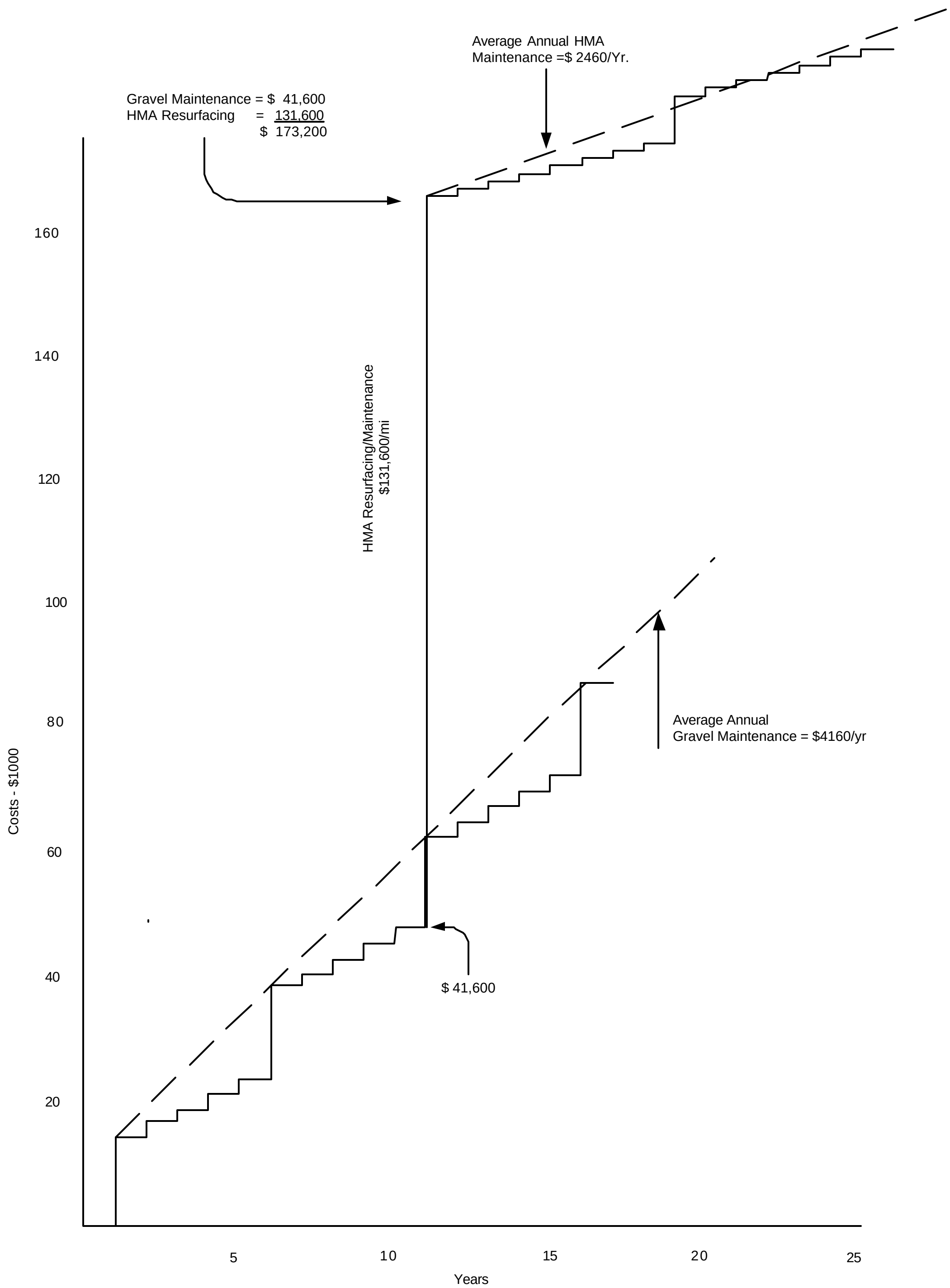
OVERVIEW

This section provides an overview of the type of analysis that is proposed for making decisions on whether or not to pave gravel roads. The details of the analysis are provided in subsequent sections. The intention is to provide a quick look at the end product of this research for readers that find that helpful.

The approach taken is illustrated in Figure 1 where the costs for a period of years are evaluated. The routine gravel road maintenance activity costs (adding gravel and re-grading and shaping) appear in a step like fashion and illustrate the annual summer activities.

Superimposed on the routine annual maintenance activities for gravel roads is an upgrade to HMA paving. HMA was chosen for use as an upgrade because cost data for maintaining this type of surface was readily available in the annual county reports that were used in the data analysis. This research refers to the HMA upgrade as a major investment to the infrastructure. These calculations could be adjusted for alternative surface upgrades. Figure 1 shows a large cost ($131,000 per mile) associated with HMA paving that occurs in year 10, and an ongoing routine annual maintenance activity in later years that is less costly than the gravel surfacing maintenance. It might be expected that the lower annual routine maintenance costs for the HMA surfacing would show a sufficiently large net reduction in expenditures to justify a decision to provide a HMA paving upgrade. The results of the following analysis will show otherwise. Nevertheless, the investment may be justified for reasons such as dust reduction or property value enhancement. These aspects of the decision will be discussed later.

When the roadway surfacing is gravel, the annual routine maintenance activities include re-grading and shaping to assure a uniform roadway cross-section and proper drainage, and re-graveling on a scheduled basis. The cost of these activities would remain fairly constant until parameters start to change. What typically changes is the traffic volumes increase, or the mix of vehicles changes, or both. In a growth area, the traffic volumes increase over time. There also tends to be an increase in the number of trucks and other heavy vehicles that service this growth area. As the traffic volumes increase, the routine annual gravel road maintenance activities increase in order to maintain the established level of service. As the activities increase so does the associated cost. When the maintenance costs escalate to a certain level and other problems become more acute, the decision is usually made to make a major investment in the infrastructure and pave the roadway with HMA or another surface. The initial investment of HMA paving is more costly than the routine annual maintenance activities for an aggregate road. But, once the HMA is in place the cost of routine annual maintenance activities is reduced. Why? There is no need to re-grade or to add additional gravel but only to provide normal ongoing maintenance activities for a paved surface. These activities would include painting traffic control lines and symbols, routine edge rutting and annual cleaning or sweeping. What typically changes is an increase in traffic, a change in the mix of vehicles, or both.



Years

Figure 1. Gravel and HMA Maintenance Costs/Mile

As one observes traffic volumes increasing along with the future need to upgrade a gravel road segment, several benefits come to mind. It may not be possible to justify an improvement to the surface based solely on cost and economic calculations. The upgrading of an aggregate road to a paved surface is a significant cost. If changes in the roadway geometry are required to meet current standards, the cost is even higher. However, despite the high initial costs there are many benefits associated with paving an aggregate road. The benefits that might be considered may include a change in the maintenance activities required, a reduction in dust generated by the vehicles, providing a smoother and safer surface, improving vehicle and driver efficiency, lower vehicle user costs, redistribution of traffic and a potential for an increased tax base because property values may increase as a result of the improvement. Some of the benefits will result in a direct impact on county budgets while others will have an indirect affect. An example of a direct effect would be diversion of traffic off of gravel roads and onto HMA roads, assuming that the amount of grading and gravel replacement can be reduced. An example of indirect effect would be property values for tracts abutting the road that increase because the road is paved allowing the county to collect more property tax. Some cost savings to neighbors and road users cannot be recovered by the government. Examples include reduced house and vehicle cleaning.

Whenever an investment of the magnitude of paving a gravel road is considered, an economic evaluation is the prudent activity to pursue. Since the costs are accrued over several years, it is necessary to evaluate the costs and alternatives at a common point in time. For the analysis in this report, the year 2004 will be the reference point in time. This is often referred to as evaluating using equivalent single payments (present worth) or equivalent uniform series of payments. The present worth of costs method combines all investments and costs and all annual expenses into a single present worth sum. This represents the sum necessary at time zero (2004) to finance the total disbursements over the analysis period. Of the alternatives compared, the one with the lowest present worth is considered the most economical. For this analysis the interest rate used is 4% and is compatible with government bonds and other government financing plans.

LITERATURE REVIEW

A search of the literature finds a wealth of information related to paved roads. Reports and studies related to gravel roads tend to be few in number. The question of when to pave a gravel road is asked by many, but difficult answer and study. There are many factors that enter into making the decision.

Bhander (1979) wrote a report showing a numerical approach based on opportunity costs of when to pave a road. Reckard (1983) wrote that not all gravel roads should become paved roads. The Kentucky Transportation Center (1988) wrote a list of 10 questions about when to pave a gravel road that should be answered in the planning stage. National Association of County Engineers (NACE) also has manuals available that relate to the design and construction of low-volume roads. Luhr and McCullough (1983) used a Pavement Design and Management System program to evaluate predicted scenarios of what the proper timing would be. Suley (1999) evaluated the performance of a number of test sections in Pennsylvania but no general conclusion was made.

The use of placing a surface treatment has been evaluated as an alternative to paving the road. Forms of these have been used over many years with varying levels of success. Minnesota has been looking at this alternative since the use of road oils in the late 1920s. Johnson (2003) explained how the concept is the same as what was used in the 1920s to what is being done with the use of oil gravel, otta seal, and chip seal in Minnesota. Others have used surface treatment for low-volume roads: such as: Thurmann-Moe and Fuistuen (1983), Scott (1996), Paige-Green and Coetser (1996), Forsberg (1997), Pinard and Obika (1997), Niegoda et. al. (2000).

Four reports indirectly related to the topic of when to pave a gravel road are: Walls and Smith (1998) wrote that a 35 year analysis period should be used and accident and work zone costs should be included. American Association of State Highway and Transportation Officials (AASHTO) (2001) has a manual available related to the Geometric design parameter involved in these roads. The USDA Forest service also has a report available related to geometrics by Evans (1995). Skorseth and Selim (2000) developed a manual that is widely referenced and gives an overview of gravel road design and maintenance.

Further information on references is provided in the annotated bibliography in Appendix A.

MINNESOTA COUNTY ROAD HISTORICAL COST ANALYSIS

The cost analysis efforts included:

1. preliminary interviews to develop data collection methods
2. data collection
3. data analysis
4. further interviews to aid with data analysis

Preliminary Interviews and Data Collection

The initial research investigation started 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: 1) routine maintenance, 2) repairs and replacements, 3) betterments, and 4) 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 was 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 for analysis.

Background information on the annual reports is provided in the following. Each year counties submit annual reports to the MNDOT SAO to document how state aid dollars were spent on 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 had reports for the time period from 1997 through 2001 that were available at the MNDOT SAO. 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.

Review of the reports and interviews with county officials exposed some limitations to the quality of the data in these reports. Some paved roads had cost entries for "resurfacing," a task that involves adding gravel to gravel roads. Some gravel road had cost entries for bituminous surface treatments (seal coats)—obviously not a cost that is expected on a gravel road. Discussions with county officials indicated some skepticism regarding accuracy in assigning costs to certain categories and certain roads. It is hoped that when such errors are spread across a sufficiently large sample, their effect on the results will be minimal.

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 2, 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.

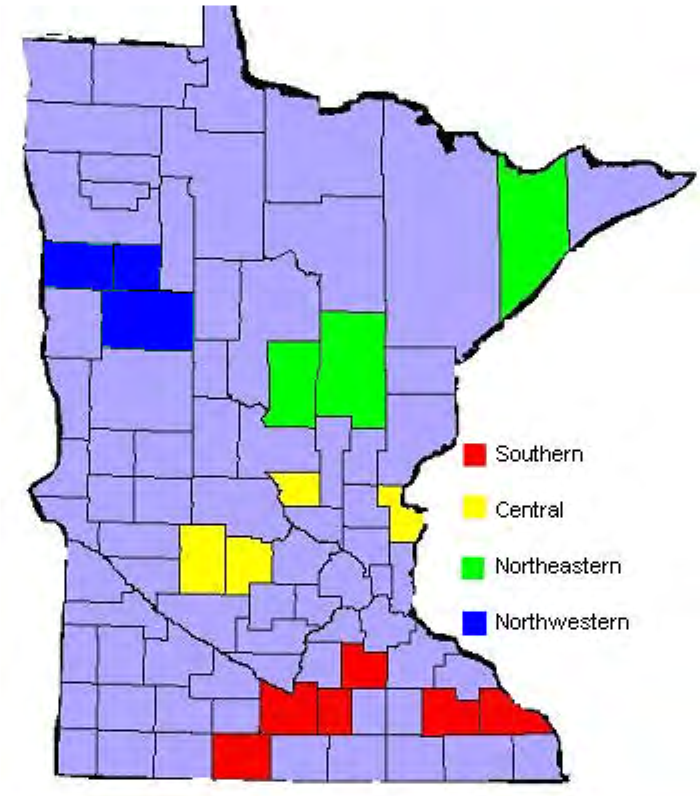


Figure 2. Minnesota Regions

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 to have 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 1997 to 2001, providing five years of data to analyze in determining representative maintenance and upgrading costs. Reports made for 2002 were not available in time for this report. 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.

The data review was completed during visits to Aitkin, Benton, Blue Earth, Kandiyohi, Meeker, Waseca and Olmsted Counties. Waseca County provided annual reports that included a detailed summary of maintenance costs by route. The Waseca County reports provided data that formulated the research team's approach to the data analysis.

The MNDOT SAO had paper reports from 1997–2001 for the other Minnesota counties. Of those reports, 40% provided data similar to that found in Waseca County reports. Although the data from Waseca County was not stratified to the extent that surface treatment costs could be broken out, the compatibility of data sets gave researchers the ability to make cost comparisons between roadway surfaces and varying traffic volumes.

The maintenance costs in the annual reports are grouped by funding source for each roadway. They are:

- County State Aid Highways (CSAH),
- County Roads (funded entirely by county funds),
- Township Roads.

This research used CSAH and county road information because cost data on these roads was readily available from the county annual reports used in the data analysis. These road classifications represent two-thirds of the county network in Minnesota and they receive a higher level of service. Since cost information data about the township roads was not readily available and roads of this type usually have the lowest level of service, they were not included in the data analysis. It is expected that the township system costs and the county system costs will be sufficiently similar so that the data collected in this study will be useful for township-level decisions.

For each road, the maintenance costs were split into five main categories (Table 1). Each category is further subdivided into two to six subcategories. This breakdown scheme matches that of the more detailed reports that counties provide to the state aid office.

MAINTENANCE CATEGORIES	ACTIVITIES INCLUDED	ACTIVITIES NOT INCLUDED
Routine Annual Maintenance	Smoothing Surface * Minor Surface Repair *	Cleaning Culverts and Ditches Brush and Weed Control Snow and Ice Removal Traffic Services and Signs
Repairs and Replacements	Reshaping * Resurfacing **	Culverts, Bridges, Guardrails Washouts
Betterments	Bituminous Treatments ***	New Culverts, Rails or Tiling Cuts and Fills Seeding and Sodding
Special Work	Dust Treatments *	Mud Jacking and Frost Boils
Special Agreements		

Table 1. Maintenance Activity Categories

***** Costs related to routine annual maintenance of roadway surface
****** Costs related to periodic maintenance of roadway surface
***Costs can be for routine or periodic maintenance of roadway surface

Some of the cost categories are affected by the roadway surface and others are not. The research team was interested in costs affected by the roadway surface. Snow and ice removal costs may be partly affected by the surface type but are not included in the analysis.

The other source of data was a set of county traffic maps that contained Average Annual Daily Traffic (AADT) counts. These maps were used to obtain the AADT used in the calculations of the individual road cost /mile/AADT. The AADT maps are prepared and provided to the counties once every four years by Minnesota Department of Transportation (MN DOT). The AADT is for roadway segments with uniform traffic volumes and do not coincide with changes in roadway surfaces. This fact made the analysis difficult when trying to associate costs to AADT levels by roadway surface type. The changes between AADT and roadway surface did not coincide at the same location on the roadway.

County Road Maintenance Costs / Gravel and Bituminous Roads

Data analysis efforts were focused on four Minnesota counties: Aitkin, Benton, Blue Earth and Kandiyohi. The research team reviewed Waseca county data during a visit with the county engineer. The Waseca data review provided the direction for the research team to evaluate the data from the other four counties. See Figure 3 for a map locating the interviewed counties.

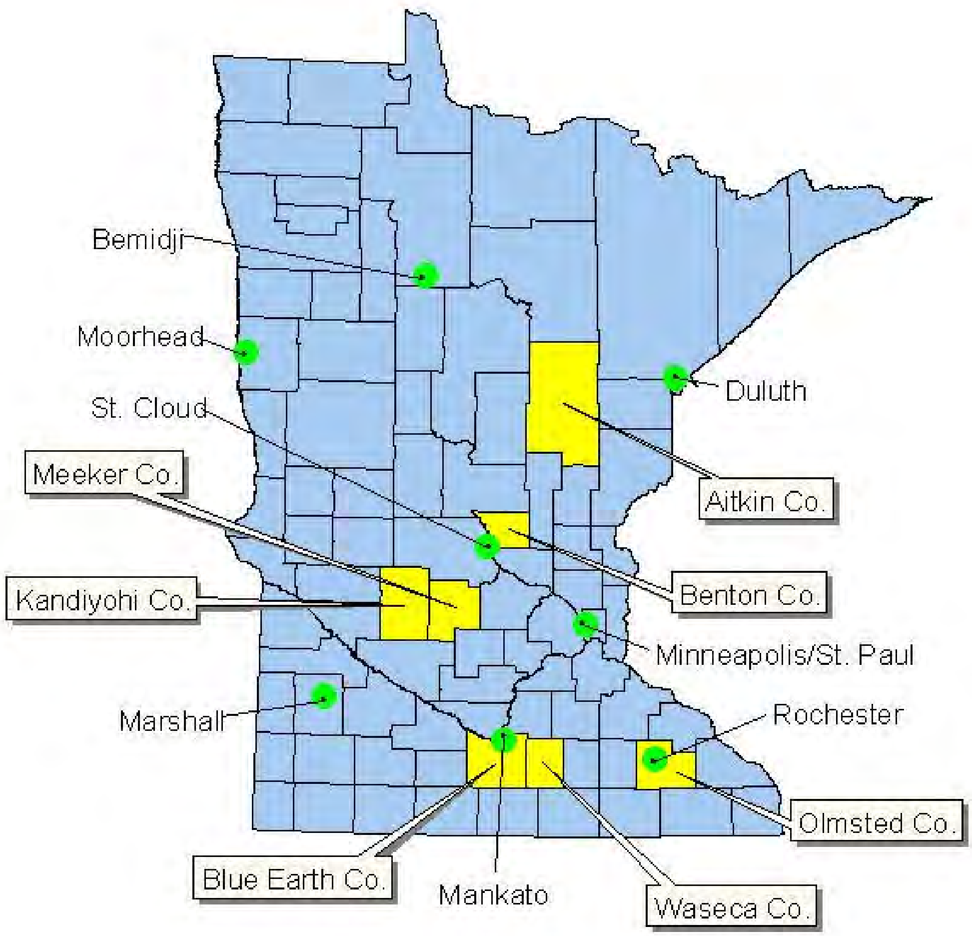


Figure 3. Location of Interviewed Counties

Waseca County:
The review of Waseca County data provided the research team with a snapshot of the data that could be used in this research. The analysis was completed using data from roads that had consistent surface type throughout the analysis period. This gave the researchers the opportunity to focus on costs associated with specific roadway surfaces. The roadways used are shown in Table 2 and their cumulative maintenance costs are shown in Figure 4.

TABLE 2. Waseca County Roadway Statistics

Road	Length of Road	Surface	AADT
Co Rd 16	2.6 miles	Bituminous	225
Co Rd 7	4.1 miles	Bituminous	1200
Co Rd 71	2.0 miles	Gravel	60
Co Rd 26	5.6 miles	Gravel	130
Co Rd 27	2.4 miles	PCC	800

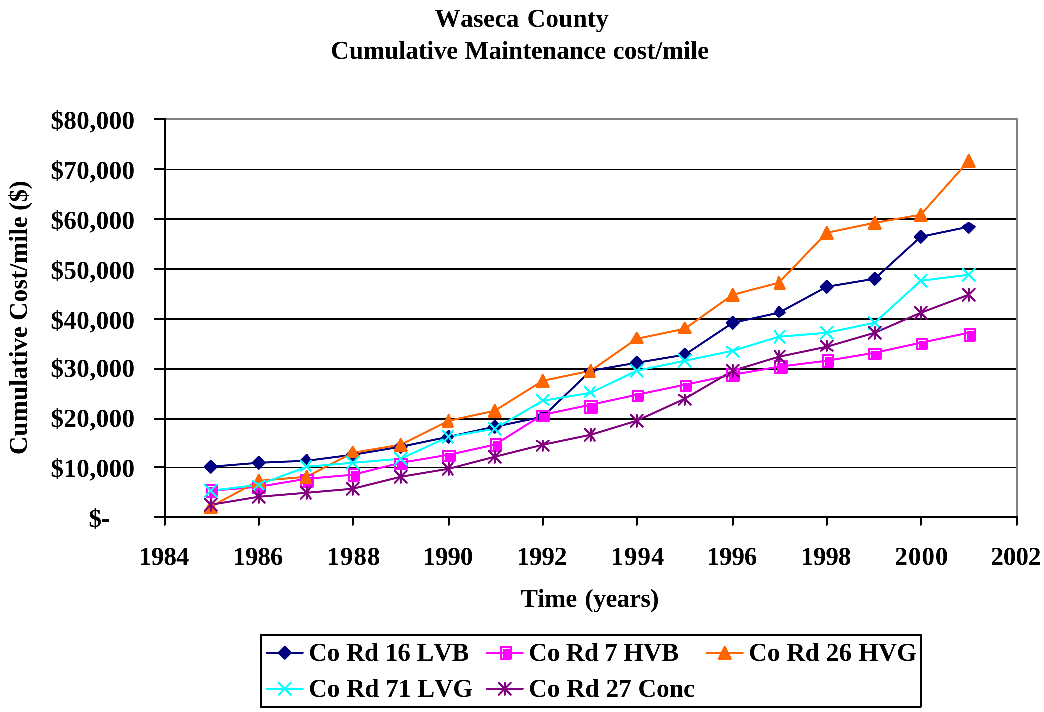


Figure 4. Waseca County Cumulative Costs/Mile (not adjusted for inflation)

Figure 4 shows that the total annual maintenance cost for gravel roads increases from low-volume (county road 71 LVG, 60 VPD) to high-volume roads (County Road 26 HVG, 130 vpd). County Rd 26 has the highest cumulative maintenance cost/mile when compared to the other roads from 1985 to 2001. Thus the hypotheses that the annual maintenance costs/mile for a gravel road increases as the AADT increases, appears to be valid. This statement needed to be verified with data for other counties and led to the next steps in the research.

Four Other Counties:

The data set from the originally selected sixteen counties, for five years (1997 – 2001), for all the CSAH and County Roads categories would be extremely large. Except for some basic analysis, it was not in the scope of this study to interview county personnel and analyze the 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 allowed for a representation of data from various regions throughout the state of Minnesota.

This data set was reduced by one county, Meeker County, after interviews were conducted to learn more about maintenance practices. Meeker County has a unique situation for the jurisdiction of the roads within the county and how they are maintained.

Meeker County only has jurisdiction over CSAH Roads. The rest of the roads are township roads but they are maintained by the county. The costs to maintain these roads is spread over all the roads and charged back to the individual townships. As a result of this unique agreement, and the cost distribution system it was decided to omit this data from the final data set analyzed.

The analysis of the data from the four remaining counties (Aitkin, Benton, Blue Earth, and Kandiyohi) provides average annual maintenance costs for gravel and bituminous (HMA) roads. A summary of the data is provided in Table 3.

The initial review of four other counties provided an average total maintenance cost/mile as shown in Table 3 and Figures 5 and 6.

County	Road Type	Miles	Total Maintenance Cost/Mile	Total Cost/Mile of Activities Influenced by Surface Type
Aitkin	Gravel	313	$3,265	$1,835
	Bituminous	189	$2,952	$846
Benton	Gravel	228	$2,706	$1,597
	Bituminous	319	$3,656	$2,268
Blue Earth	Gravel	297	$3,614	$1,997
	Bituminous	412	$4,356	$2,235
Kandiyohi	Gravel	220	$2,167	$1,710
	Bituminous	407	$1,917	$636
All Four	Gravel	1058	$3,024	$1,827
	Bituminous	1327	$3,341	$1,619

Table 3. Four County Maintenance Costs/Mile (approximate average date: 1999)

The total cost per mile was calculated from the cost history data. The costs/mile associated with the surface type included costs for smoothing surface, minor surface repair, reshaping, resurfacing, and bituminous treatments previously shown in Table 1.

A review of Figures 5 and 6 shows that the maintenance costs/mile for Kandiyohi County are lower than the other three. Based on the data available at this time in the research, there is no explanation why the maintenance costs/mile are less. There may have been recording errors when the cost reports were done. The cause of the low maintenance cost will be addressed in the next phase of the research, when the counties are interviewed.

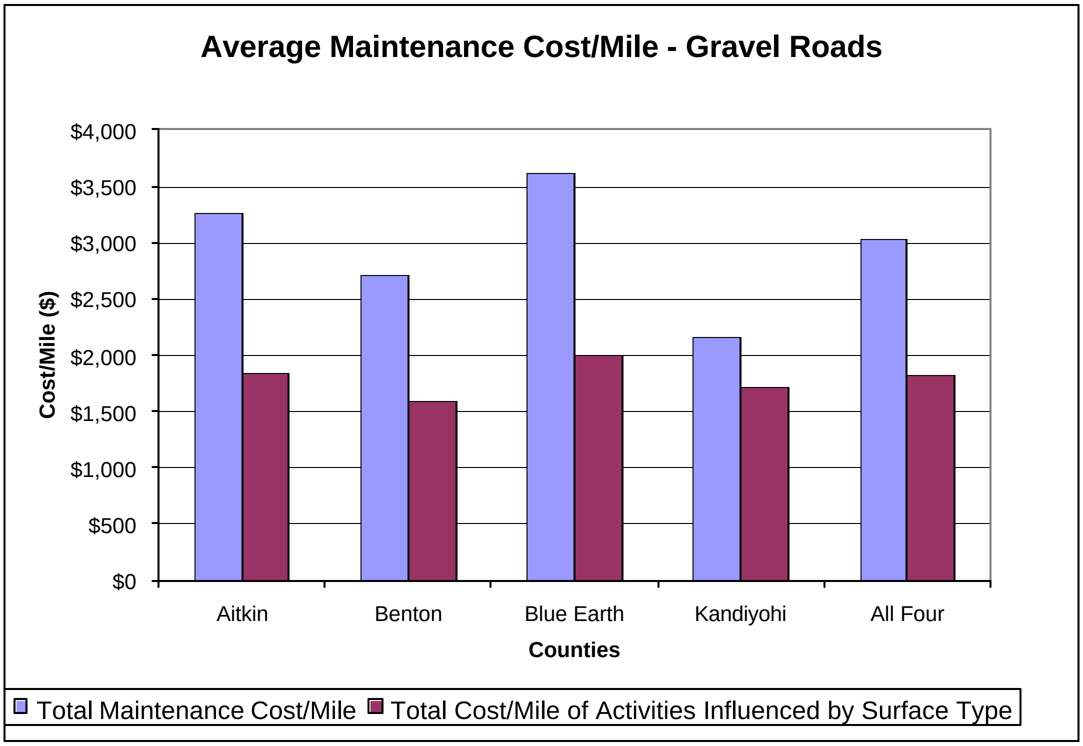


Figure 5. Average Maintenance Costs/Mile – Gravel Roads

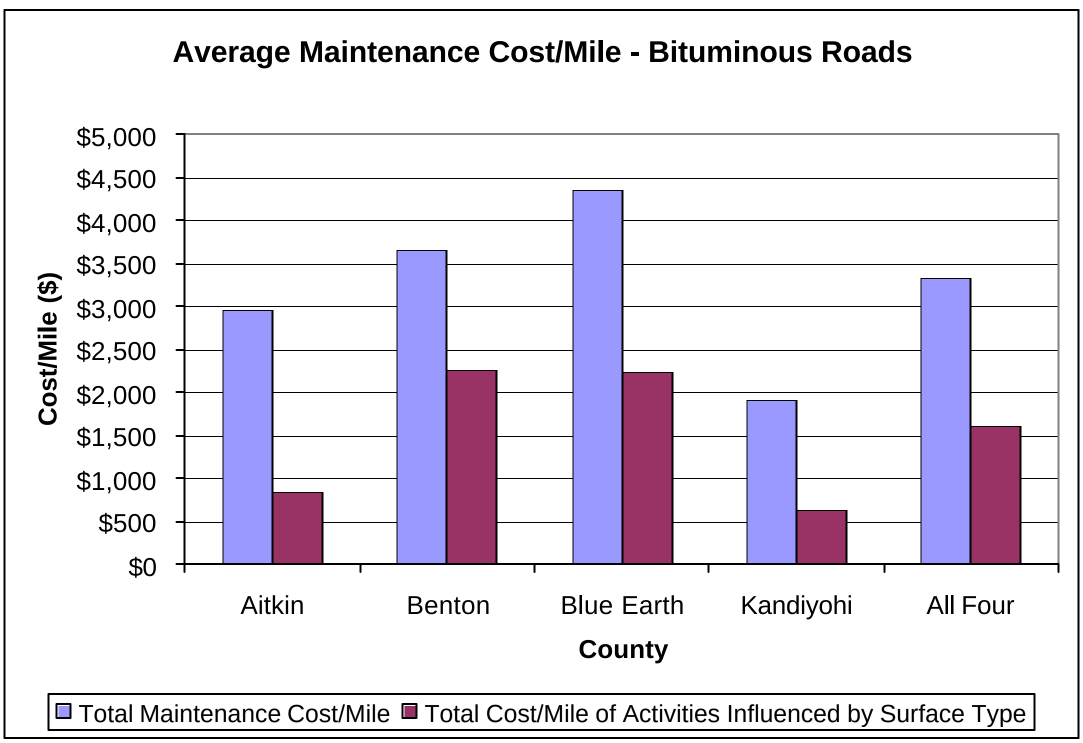


Figure 6. Average Maintenance Cost/Mile – Bituminous Roads

The annual maintenance costs recorded for gravel roads in these four counties is higher than the annual maintenance costs for bituminous roads. By looking at the cumulative costs over a period of years, the annual cost savings in maintenance activities between gravel and HMA can be illustrated. Over a 20-year period, the annual maintenance costs for gravel roads are higher than for bituminous roads. The researcher looked at this difference: the lower bituminous road maintenance costs as a potential justification to upgrade a gravel road to bituminous surfacing.

Minnesota County Road Cost vs Average Annual Daily Traffic (AADT)

With the use of traffic maps, the average annual daily traffic (AADT) for each segment of road was added to the data set. The AADTs were grouped in the categories shown in Figure 7 to identify the relationship between traffic level and maintenance costs.

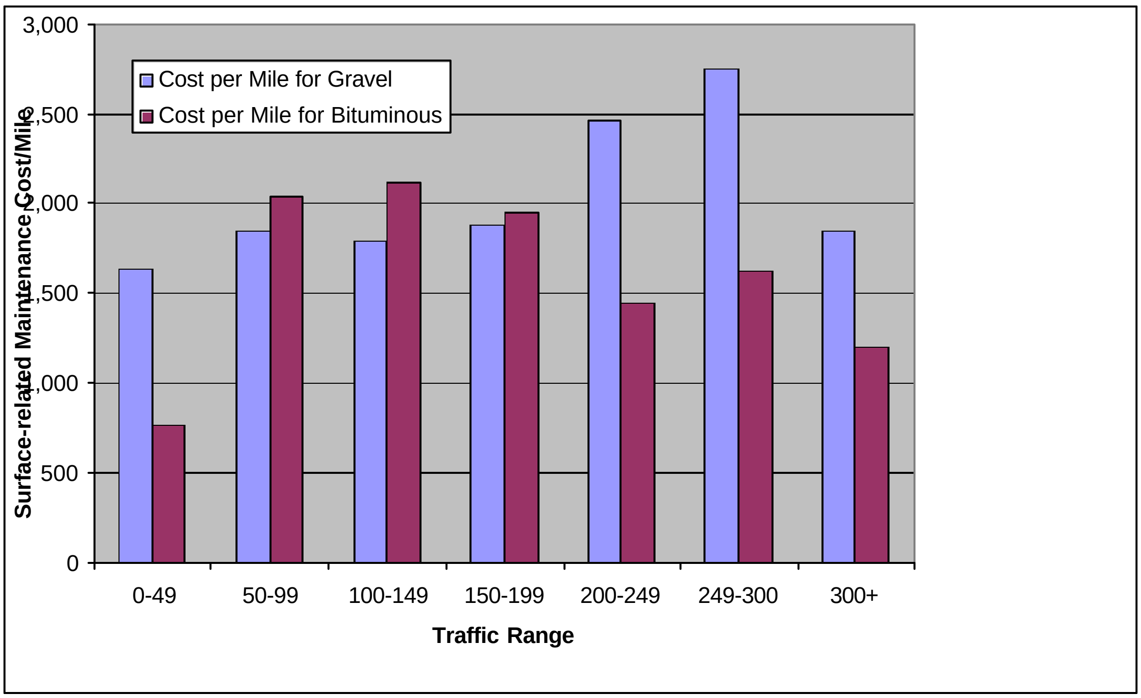


Figure 7. Five-Year Average Four-County Surface-Related Maintenance Cost/Mile vs AADT

Table 4 shows the approximate average number of miles of gravel and paved roads for various traffic volume categories as well as the cost per mile average over the five-year period from 1997 to 2001. The number of miles in each category is necessarily an approximation because roads occasionally change traffic categories from one year to the next and some gravel roads are paved—thus changing surface categories. Notice that there are few miles of paved road in the low-traffic categories and few miles of gravel road in the high-traffic categories. Also notice that the category from 150 to 199 is the closest to having 50% of its roads paved. This would indicate that the average current practice in these four counties is to have the majority of the roads paved by the time they reach this traffic level.

Traffic Volume	Cost per Mile for Gravel	Gravel Mileage	Cost per Mile for Bituminous	Bituminous Mileage	Total mileage	Percent Bituminous
0-49	1,639	252	767	3.6	256	1%
50-99	1,851	359	2,041	33.8	393	9%
100-149	1,788	143	2,116	70.6	214	33%
150-199	1,878	71	1,958	84.2	155	54%
200-249	2,466	34	1,446	120	154	78%
249-300	2,746	1	1,623	109	110	99%
300+	1,847	10	1,199	887	897	99%

Table 4. Surface-Related Maintenance Cost per Mile vs AADT for Four Counties from 1997 to 2001

Figure 7 shows an upward trend in the costs per mile for gravel roads as traffic increases—except for the highest level of traffic. Figure 7 also indicates that bituminous maintenance costs also increase with traffic and are comparable to those for gravel at 150 to 199 AADT. Then as traffic increases, costs decrease. Examination of more detailed data shows that bituminous surface treatments are a relatively large part of the cost of road maintenance in the range of 75 to 200 AADT. It may be that roads with this traffic range receive more of these treatments than roads in higher traffic ranges.

Since there are so few low-volume bituminous roads and high-volume gravel roads, these categories are represented by only a few road segments. When a category is represented by only a few segments, misjudgment errors in recording data to those entries could have a relatively large effect on the outcome. Thus strong reliance should not be placed on the results from the low-volume bituminous and the high-volume gravel categories. This is unfortunate, because a comparison between the high-volume gravel category and high-volume bituminous category would be of most interest for this investigation.

Limitations Regarding Historical Analyses

The quality of historical cost analyses are limited by the availability and quality of historical data. During interviews local officials mentioned that due to time limitations, it is unlikely that all the data is recorded by field forces in the proper categories. This was apparent because the data showed that maintenance activities for bituminous roads were sometimes charged to gravel roads and vice versa. Few jurisdictions have historical data that is as good as the data that was analyzed for this report. Clearly, methods are needed to check historical data and to develop an analysis when good historical data does not exist. The following section of this report shows how cost estimating can be used as an alternative to historical cost analysis.

MAINTENANCE COST ESTIMATING METHOD

Under certain circumstances, it may be desirable to predict future maintenance costs with a cost estimate. Such circumstances may include situations where historical data is lacking or unreliable. Shifts in material sources and maintenance methods may also render historical data to be of limited use. Cost estimates may also be used to vet historical data. Also, local official can use the methods presented herein to develop cost estimates using their local material sources and their methods and equipment and then compare them historical data provided in this report.

The reported county cost data discussed earlier in this report showed some variance. This variance may be due to the location within the state or the local availability of materials and contractors. For purposes of economic evaluations, cost estimates were developed for gravel maintenance and for HMA paving and the associated maintenance costs.

The cost estimates for gravel road maintenance assumed a roadway cross-section as shown in Figure 8. The costs estimated include ongoing grading activities and re-graveling every five years. Table 4 tabulates the calculations and Figures 9 and 10 graphically illustrate the estimated expenditures.

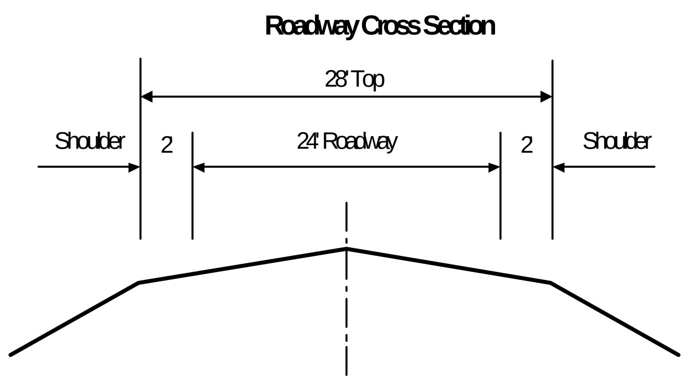


Figure 8. Typical Roadway Cross Section

The following calculations are for yearly maintenance costs for one mile of road. They assume routine grading activities each year and re-graveling every five years with the cycle repeating. The cost estimates were made to provide a comparison for the cost data recorded by the counties. The following includes a list of the assumptions made, and calculations of the motorgrader work hours, maintaining/grading costs, and re-graveling/surfacing costs. Many aspects of these calculations are based on methods presented in the Caterpillar Performance Handbook (1999)

a) Assumptions

- A 24-foot top roadway one mile long: (24 ft.)(5280 ft.) = 126,720 ft^2 of surface
- A nominal 2 inches of new gravel is assumed for re-graveling, which requires 1000 yd^3 /mile or 1000 ton/mile
- The ratio of thickness of loose gravel to compacted gravel is 1.28:1; therefore, a 2-inch compacted gravel lift requires placement of 2.56 inches of loose gravel, Skorseth and Selim (2000), pp. C1-C2.
- Based on conversations during interviews with county personnel, gravel costs approximately $7.00/cubic yard
- The road is graded 3 times per month from April to October, for a total of 21 times
- The cost for the motorgrader is $40/hr – including fuel, oil, etc.
  - The motorgrader travels at about 4 mph during grading operations
  - Assume a 12 foot moldboard with carry angle of 60 degrees
  - 3 passes of the motorgrader are needed per mile
- Motorgrader operator at $30/hr – includes fringe benefits
  - The motorgrader operating at an efficiency of a 45 minute-hour (0.75). Assumes time spent deadheading to and from maintenance areas and the standard construction equipment operating efficiency of a 50 minute-hour
- Trucks at $40/hr – includes fuel, oil, etc.
  - 12 cubic yard capacity
- Truck driver at $25/hr – includes fringe benefits
  - Round trip for 1 load of material takes about 1.25 hours

b) Calculation of Motorgrader Work Hours

$$A = S \times (L_e - L_o) \times 5280 \times E$$

A: Hourly operating area (ft^2/hr)
S: Operating speed (mph) = 4 mph
L_e: Effective blade length (ft) = 10.4 ft (from Caterpillar Performance Handbook)
L_o: Width of overlap (ft) = 2.4 ft for 3 passes
E: Job efficiency = 0.75

$$A = 4 \text{ m/hr} \times (10.4 \text{ ft} - 2.4 \text{ ft}) \times 5280 \text{ ft/mi} \times 0.75$$

$$A = 126{,}720 \text{ ft}^2/\text{hr}$$

Time (t) to blade 1-mile road with 24 foot wide top:

$$t = \frac{\textit{Surfacing Area}}{\textit{Motorgrader rate}}$$

$$t = \frac{126{,}720 \text{ ft}^2}{126{,}720 \text{ ft}^2/\text{hr}} = 1.00 \text{ hrs}$$

or

Working at an efficiency of 0.75 and operating at 4 mph means the motorgrader will take one pass on 3.0 miles of road in one hour. If three passes are needed per mile of road, then the motorgrader can cover three passes on 1.0 mile of road in one hour.

Blade 1-mile stretch of road 21 times throughout the year.

Time (T) = Annual time spent on 1-mile of roadway:

T = 1.00 hrs./mile x 21 miles = **21.0 hours**

c) Maintaining/Grading Costs: (for 1 year)

Equipment: $\left(\$40/_{hr}\right) \times 21.0\text{ hrs} = \$840 \approx \$800$

Labor: $\left(\$30/_{hr}\right) \times 21.0\text{ hrs} = \$630 \approx \$600$

Total: $1400/year

d) Re-graveling/Surfacing Costs: (done every 5 years, watering and compaction not included)

Material: $\left(\$7.00/_{yd^3}\right) \times \left(1000\text{ yd}^3/_{mile}\right) = \$7000$

Equipment: $\#\text{ loads} = \left(1\text{ load}/_{12\text{ yd}^3}\right) \times \left(1000\text{ yd}^3/_{mile}\right) = 83.33 \approx 84\text{ loads}$

$84\text{ loads} \times 1.25\text{ hrs} = 105\text{ hrs}$

$105\text{ hrs} \times \left(\$40/_{hr}\right) = \$4200$

Labor: $\left(\$25/_{hr}\right) \times 105\text{ hrs} = \$2625 \approx \$2600$

Total re-graveling/surfacing costs= $7,000 + $4,200 + $2,600 =$13,800

Table 5 shows the primary costs for maintaining a gravel road, grading and resurfacing, for a five year re-graveling cycle. Notice that the majority of the costs associated with maintaining a gravel road occur when gravel is hauled to the road for resurfacing. Depending on the quality of the gravel being used and the amount of gravel lost each year, this resurfacing operation may occur at different intervals for each county.

Year	1	2	3	4	5	6	Totals
Grading							
Equip.	$800	$800	$800	$800	$800	$800	$4,800
Labor	$600	$600	$600	$600	$600	$600	$3600
Resurfacing							
Materials	$7000					$7000	$14,000
Equip.	$4200					$4200	$8400
Labor	$2600					$2600	$5200
Annual Totals	$15,200	$1400	$1400	$1400	$1400	$15,200	$36,000
Cumulative Costs		$1400	$2800	$4200	$5600	$20,800	

Table 5. Maintaining/Grading and Re-graveling/surfacing Costs for Five-Year Cycle

The cost of a typical five-year maintenance cycle can be found by summing the costs for years 2, 3, 4, 5 and 6 and obtaining $20,800. The average annual cost can be calculated by dividing by five years. The result is $4160 per year. This cost is larger than the costs that resulted from the historical cost analysis, even though a five-year re-graveling cycle was used in the cost estimate. Based on interviews, a five-year cycle is the upper bound for re-graveling roads where traffic volumes exceed 100 vehicles per day. There are many possible explanations for this difference. One is that not all the effort that should be charged to maintaining these roads is being charged. Alternatively, it may be that less effort is actually expended in gravel road maintenance that was contemplated in the cost estimate.

ROADWAY MAINTENANCE COST ECONOMIC ANALYSIS

An economic analysis can assist officials in making a decision about whether or not to upgrade a gravel road. An example is given here that compares the cost of maintaining a gravel road with the cost of upgrading and maintaining an HMA road. The example can be modified to reflect the cost and timing of many typical situations. In this example, the cost estimate from Table 5 was used for gravel roads. This is because the authors deemed that the cost estimate was more reliable for a gravel road that is typically upgraded to a paved surface: one with a traffic volume ranging from 100 to 200 vehicles per day. For the HMA road, historical costs were used. This is because the authors did not identify predictable maintenance operations for HMA roads whose cost could be estimated. Therefore, the historical data was the best available for the purpose.

Figure 9 provides a graphical representation of the estimated cumulative costs for maintaining a gravel road. The data came from the calculations shown in Table 5 "Maintaining/Grading and Re-graveling/surfacing Costs for Five-Year Cycle." The small steps on the graph represent the routine maintenance activity of grading the surface, which is estimated to be $1400 per mile per year. The larger steps indicate the re-graveling activity and the routine surface grading that occurs every five years. This is estimated to cost $15,200 per mile.

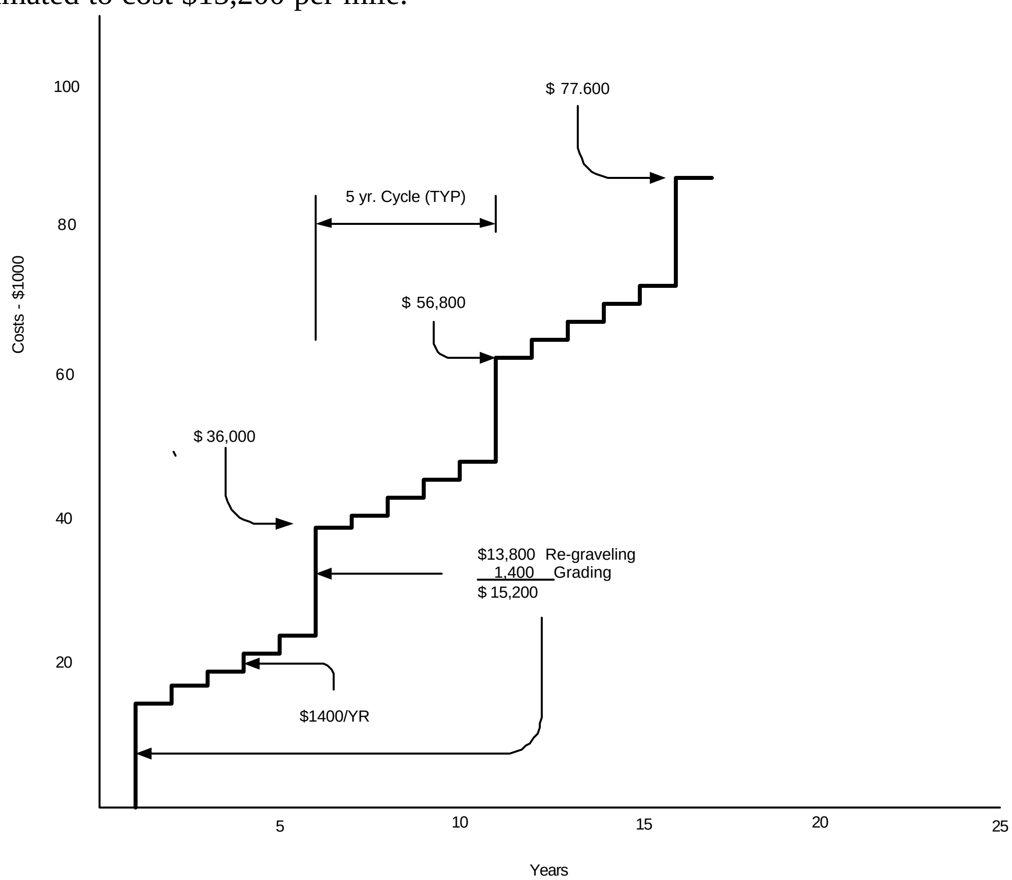


Figure 9. Gravel Road Maintenance Costs/Mile – Five-Year Cycle

The initial investment is shown in year 1 for the amount of $15,200 per mile (includes re-graveling and grading costs). This expenditure is estimated to occur every 5 years, or in years 6, 11, 16, etc. In between these years, routine grading activities occur.

Figure 10 shows what the average annual expenditure would be over several years. The sum at any point along the line, in Figure 10, is divided by the number of years to that point and average annual gravel road maintenance costs/mile for a five-year cycle is calculated. The average expenditure is estimated to be $4160 per year. This figure will be compared to a similar figure for HMA paving.

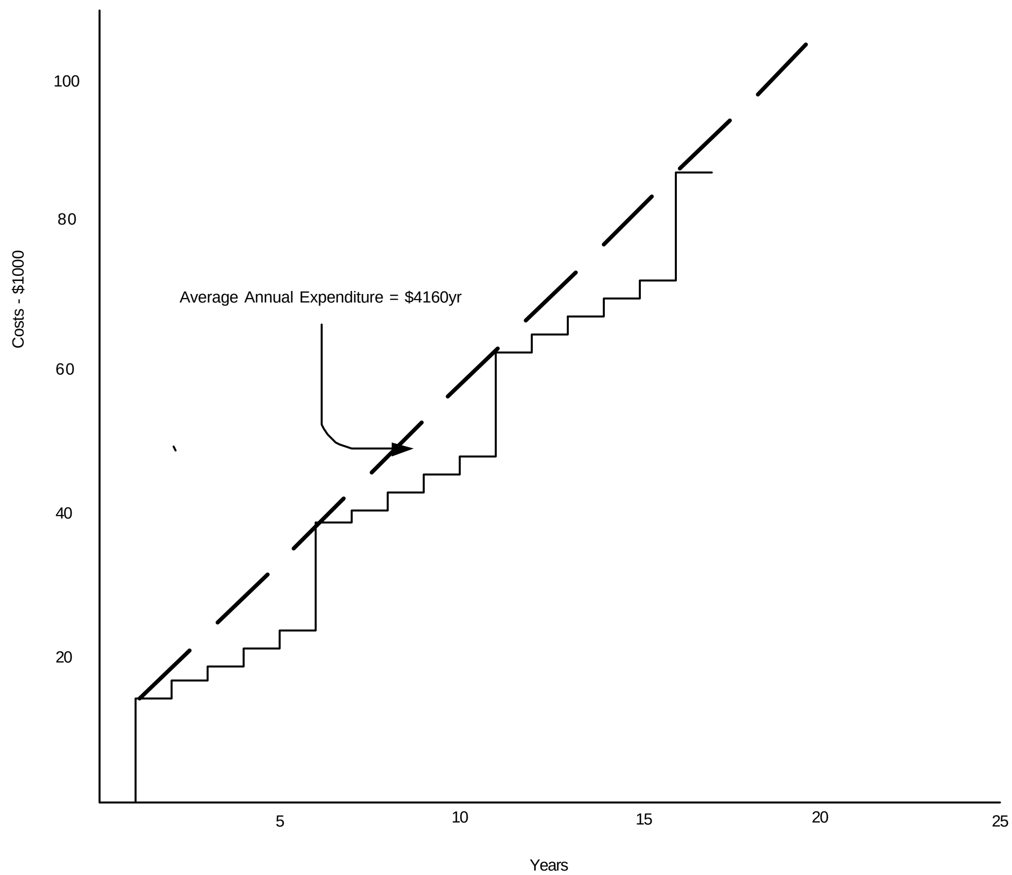


Figure 10. Average Annual Gravel Road Maintenance Costs/mile – Five-Year Cycle

Hot Mix Repaving (HMA)

Estimating the cost of upgrading a gravel road to a higher surface is the next step in the analysis. The analysis assumes an upgrade to HMA paving because appropriate cost information was readily available to the research team. Other upgrades may be more appropriate given the local conditions and the budget available. The scenario of upgrading to HMA paving will serve as a benchmark for one of the higher cost options that are commonly implemented by local jurisdictions. The costs shown in Table 5 were obtained by reviewing the county cost data shown in Figure 6 "Average Maintenance Cost/Mile – Bituminous Roads" and establishing the annual maintenance expenditure at $1600 per mile/ per year. The HMA resurfacing costs vary across the state of Minnesota and for the purposes of analysis, a cost of $130,000 per mile was utilized. This estimate was reviewed by the research project advisory committee who stated that it is a fair representation of the cost.

Year	1	2	3	4	5	6	7	8	Totals
Maintenance	$1600	$1600	$1600	$1600	$1600	$1600	$1600	$1600	$12,800
Resurfacing	$130,000							$6000	$136,000
Annual Totals	$131,600	$1600	$1600	$1600	$1600	$1600	$1600	$7600	$148,800
Summary	$131,600	$133,200	$134,800	$136,400	$138,000	$139,600	$141,200	$148,800	

Table 6. HMA Maintenance/Seal Coat Costs for Seven-Year Cycle

A summary of the estimated cost to pave and maintain an HMA road is shown in Table 6. The HMA surface is assumed to be constructed in year one for $130,000 per mile and maintained at a cost of $1600 per mile for each year afterward. Seven years beyond the initial HMA surfacing, a seal coat is applied at an estimated cost of $6000 per mile. It is also necessary to continue maintenance expenditures of $1600 per mile per year during this seventh year. The seal coat application is repeated on a seven-year cycle and continues until the road is selected for another form of repair which may be an overlay or cold-in-place recycling. The information found in this table is also shown in a graphical representation in Figure 11.

The estimated costs from Table 6 are shown in Figure 11. The scenario that is being developed assumes the HMA surface would be applied during year 10.

Between years 1 and 10 many things may occur along with the grading activities. It may be that the traffic volumes are at or beyond the 100 vpd threshold and are approaching 200 vpd, a point at which improvements are justified. Figure 10 assumes that re-graveling activities will take place during years 1 and 6 and the normal grading activities occur during the other years. During years 1 to 10, cost estimates for HMA surfacing are developed and included in the county's budget for year 10.

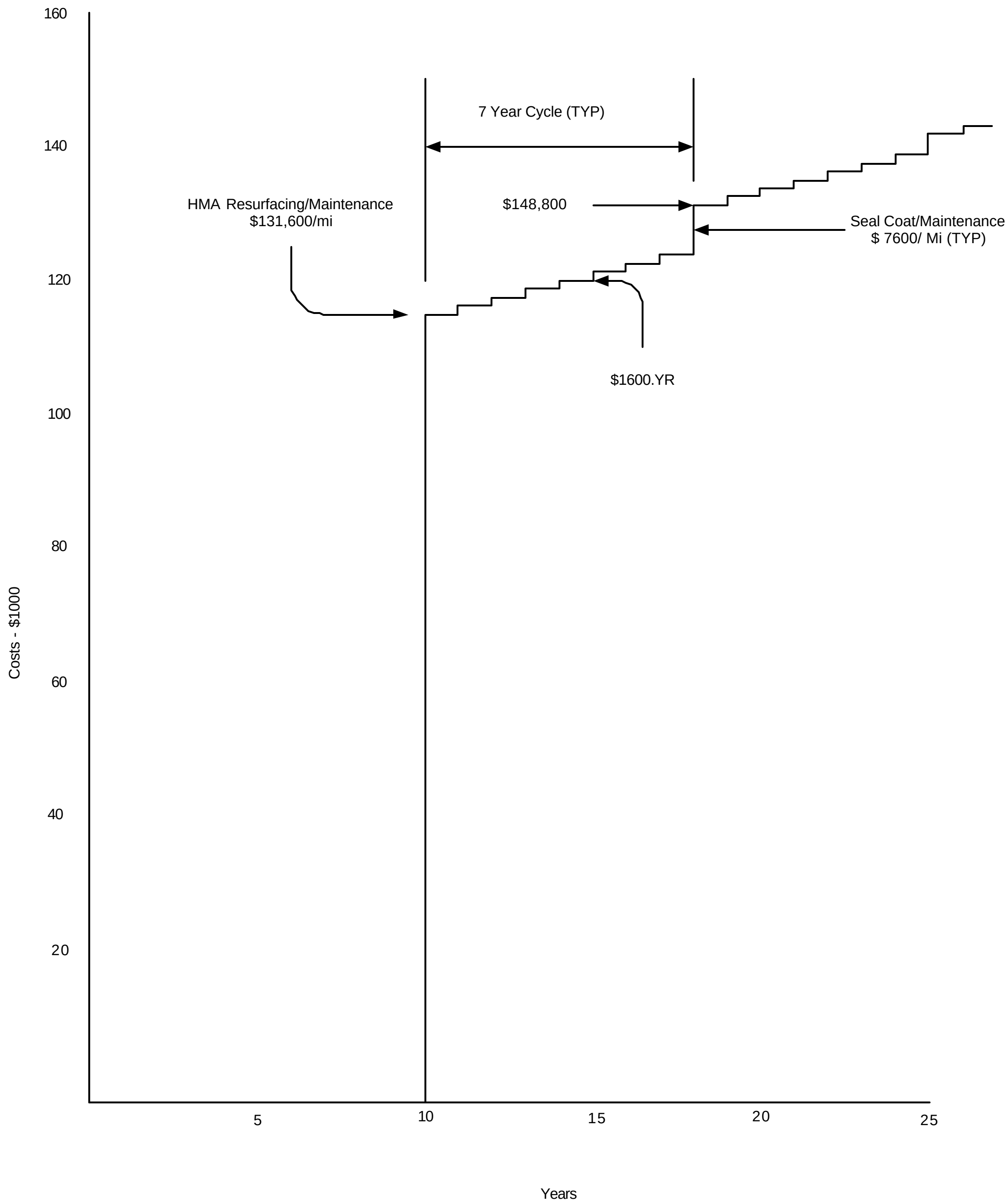


Figure 11. HMA Resurfacing/Seal Coat Maintenance Cost/Mile– Seven-Year Cycle

The initial HMA investment is $131,600/mile in year 10. Routine HMA surface maintenance activities occur over the next 6 years. In year 17, a seal coat is applied to the surface at the annual maintenance cost of $7,600 / mile. This routine continues for several years and a seal coat is applied every 7 years.

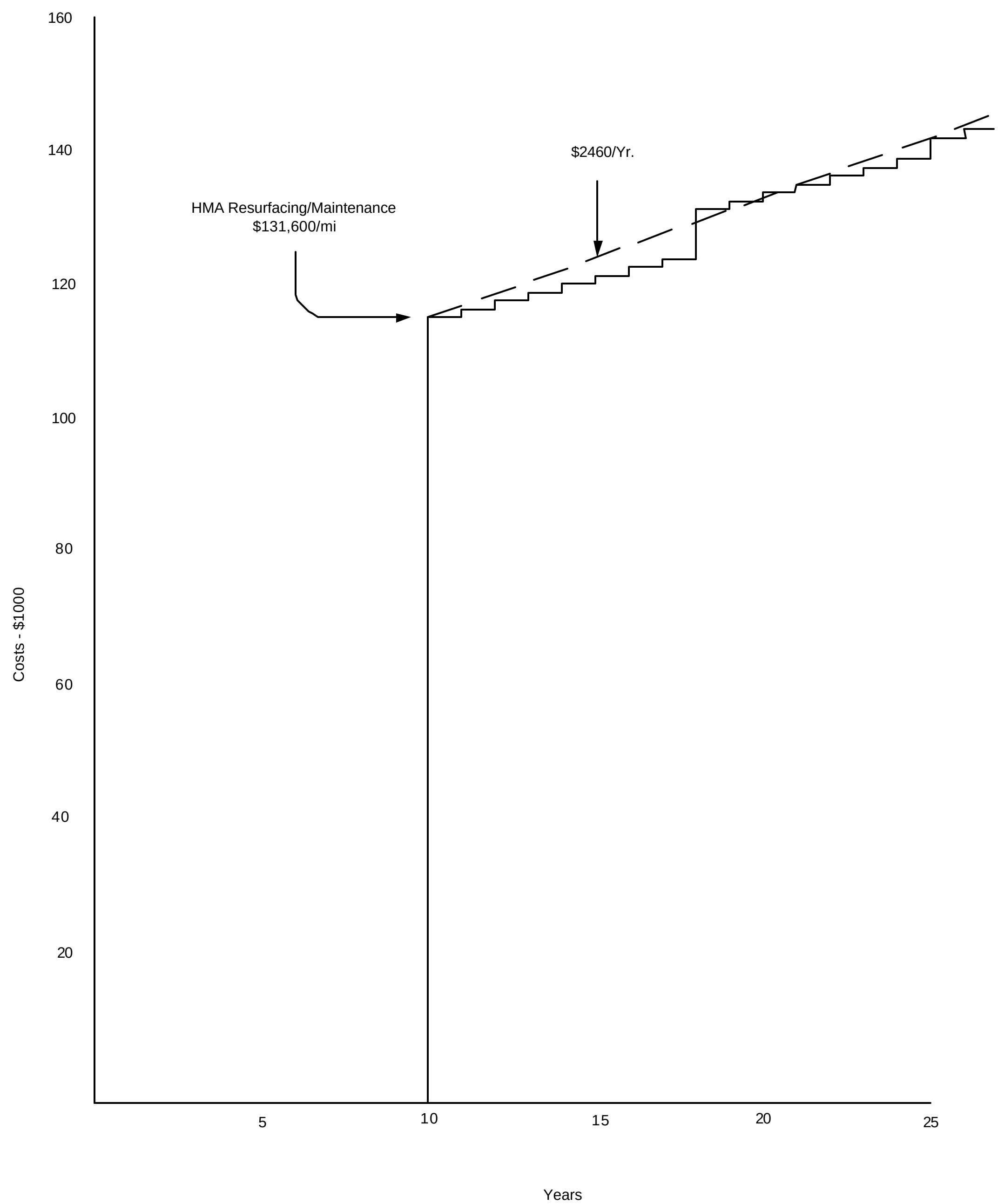


Figure 12. Average Annual HMA Maintenance Costs/Mile – Seven-Year Cycle

Figure 12 shows what the average annual expenditure would be over several years. The sum at any point along the line in Figure 11 is divided by the number of years to that point and average annual HMA maintenance costs/mile for a seven-year cycle is calculated. The average expenditure is estimated to be $2460 per year. This compares to a similar activity for gravel road maintenance of $4160 per year.

A roadway maintenance cost history can now be assumed. Figure 13 shows the gravel surfacing maintenance beginning in year 1 and the HMA surfacing occurring in year 10. By viewing the maintenance costs in this way we can see a cost profile covering several years. It is also possible to look at the average annual maintenance costs over several years, as shown in Figure 14.

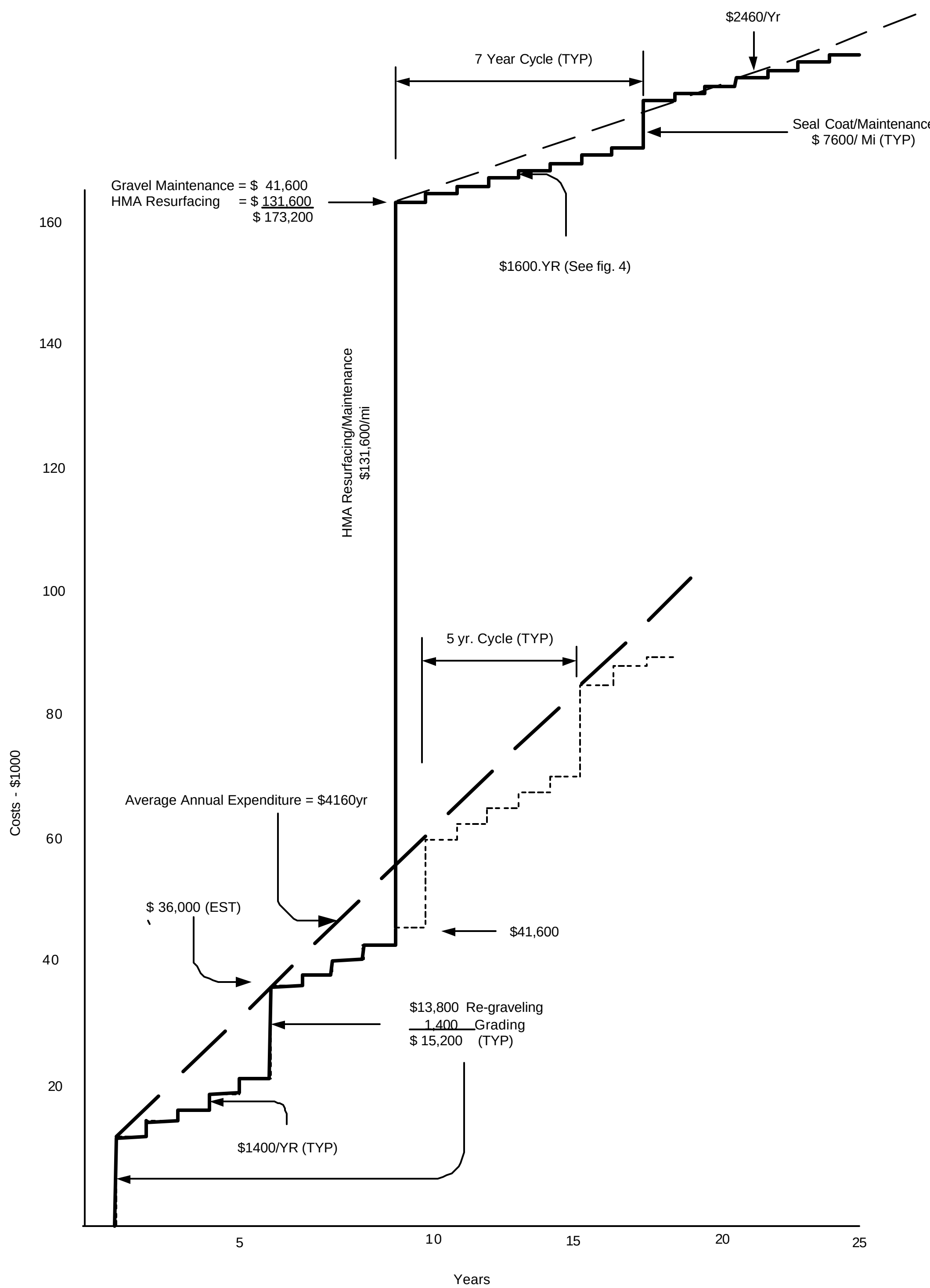


Figure 13. Gravel and HMA Maintenance Cost/Mile

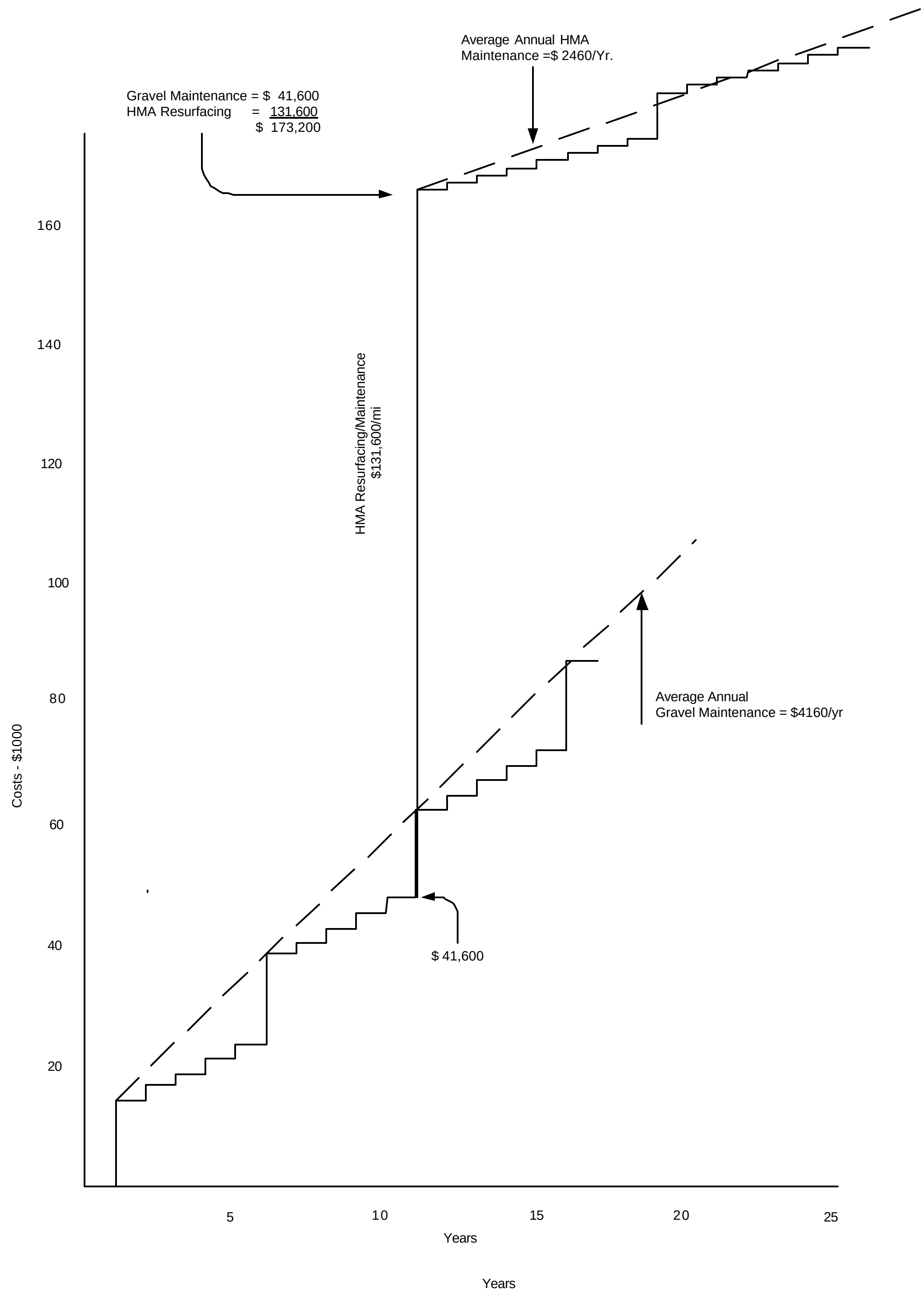


Figure 14. Average Annual Gravel and HMA Maintenance Costs

The calculated average maintenance costs for gravel and HMA is shown in Figure 14. The average annual costs for the HMA resurfacing is $2460 / yr (includes seal coat every 7 years) and is less than the average annual costs of $4160 for gravel (includes re-graveling ever 5 years).

The question many ask is this: Is the difference between HMA and gravel average annual maintenance costs enough to justify the HMA resurfacing investment? This question is best answered after careful consideration of all aspects of the decision. The next secion reviews several of these other considerations— many of which are important to citizens, though their cost and benefits are not easily quantified.

CONSIDERATIONS FOR ROADWAY SURFACING DECISIONS

As one observes the traffic volumes increasing and the future need to upgrade a gravel road segment becomes apparent, several benefits come to mind. One of the first is the cost savings for not having to spend the resources for ongoing gravel road maintenance. But, it may not be possible to justify an improvement to the roadway surface based solely on economic calculations. The upgrading of an aggregate road to a paved surface is a significant cost. If changes in the roadway geometry are required to meet current standards, the cost may be even higher. However, despite the high initial costs, there are many benefits associated with paving an aggregate road. The benefits that might be considered include a change in the maintenance activities required, a reduction in dust generated by vehicles, providing a smoother and safer surface and improving vehicle and driver efficiency, a redistribution of traffic, and a potential for an increased tax base. Some of the benefits will result in a direct impact on county budgets while others will have an indirect affect.

Interviews with county officials confirmed that residents, land owners, and road users prefer paved roads. Many individuals who build on the urban fringe formerly lived in urban areas and come with expectations of service typical of an urban area, including a paved road surface. Desirable rural residential areas surrounding lakes and area of scenic beauty often attract landowners who desire a paved road surface. Some officials commented that traditional rural families seem to be making more trips for social, business, and educational reasons, adding to the traffic load and making more paved roads desirable.

Changes in Maintenance Activities:

When paving an aggregate road, the costs of maintenance activities will change. For example, grading and graveling activities will cease. Another reduced activity would be applying dust suppressants. The quantity of gravel placed is reduced and possibly the amount of equipment needed. These reduced or changed maintenance activities result in a direct benefit to the county.

When upgrading a gravel road to a paved (HMA) road, the costs per mile for some activities change because of two things: (1) Road users expect a higher level of service for a bituminous road compared to a gravel road (especially snow and 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 and weed control are higher on a paved road because vegetation needs to be kept cut back further from the edge of the road. This is because of the increased speeds on a paved road. With increased speeds, drivers need an increased sight distance along the road and clear zone to prevent 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 and ice removal is higher on paved roads because more time is spent plowing them. Crews plowing snow make multiple passes with a snowplow on a paved road to clear the surface of snow, while on a gravel road only two passes normally occur. Also, chemicals and abrasives are placed on paved roads, at least on curves, hills, and at intersections, if not on the entire road. On gravel roads chemicals and abrasives are rarely used, if at all, because travel speeds are slower and gravel may provide additional traction. The 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. Costs also change based on the county's snow plowing policy. Some counties start plowing with as little as 1 inch of snow while others wait to plow until there is approximately 3 inches. Crews typically work a 10 to 16 hour day and then come back the next day to complete additional work. Whether or not bare pavement is required varies from county to county. Policies range from mostly bare pavement, to only bare pavement required in the wheel tracks, to intermittent bare pavement sections. Bare pavement issues are dictated by the functional classification of the road and the AADT. Those roads with higher traffic volumes and those classified as major arterials have a more stringent bare pavement policy than the roads with lower traffic volumes and those that are classified as minor arterials or local roads.

For traffic services, costs are normally higher because there are more signs required along a paved road and pavement markings and other traffic control devices are generally provided. More signs are used to identify the road and 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 used on a paved road than on an aggregate road. Finally, luminaries are typically placed at paved road intersections, to increase visibility and safety, along with four-way flashing lights or other traffic control devices. As a result of a county's snow plowing policy, pavement markings may be worn and thus need to be repainted each year. The plowing operations may also lead to inadvertently destroying more signs and other traffic control devices.

Reduction of Fugitive Dust:

When an aggregate road is paved, the traveling public creates no dust. This would be an indirect benefit to the county and to the adjacent homeowners. With no dust coming from the roadway, surrounding homes are kept cleaner and the living conditions are improved. Improved living conditions may reduce asthma, allergies, and other breathing health-related issues. In addition, homeowners would spend less time cleaning their homes. The environmental benefits include reduced air and water pollution, and crops and vegetation are not covered with dust. Since no dust is being produced, there is no need to spend resources on calcium chloride or other dust suppressants. The homeowner can use the savings for other purposes.

Safer Surface:

Paving an aggregate road creates a surface with improved skid resistance and reduced stopping distance. The coefficient of traction for rubber tires on a paved road (a specifically concrete value is not given for HMA) is 0.90, compared to a gravel road (loose) which is 0.36 (Caterpillar, 1999). The coefficient of traction is the ratio of the horizontal force that would cause tires to move relative to the road surface to the vertical force on the tire. An added benefit is that drivers will not experience soft spots of the surface or loose gravel that can pull a vehicle to the side.

Improved Vehicle and Driver Efficiency:

Better vehicle efficiency is obtained when a vehicle operates on a smooth hard surface as opposed to a loose gravel surface. The rolling resistance for a vehicle on a paved road is 1.5 % of its weight. Compare that value to a road with light surfacing that is maintained regularly: 3% on loose sand or gravel: 10% (Catepillar 1999). The decrease in rolling resistance of a paved road results in a decrease in fuel consumption. The paved surface creates a smoother ride and reduces the amount of wear and tear on a vehicle's tires and suspension system. The vehicle filters (air, fuel and oil) are kept cleaner in a vehicle driven on a paved roadway and result in improved fuel efficiency and lower operating costs. A paved roadway promotes increased travel speeds resulting in shorter travel times and timesaving for the vehicle occupants. These savings do not directly enhance revenue for the local jurisdiction; however, citizens benefit by saving money on maintaining vehicles.

Redistribution of Traffic:

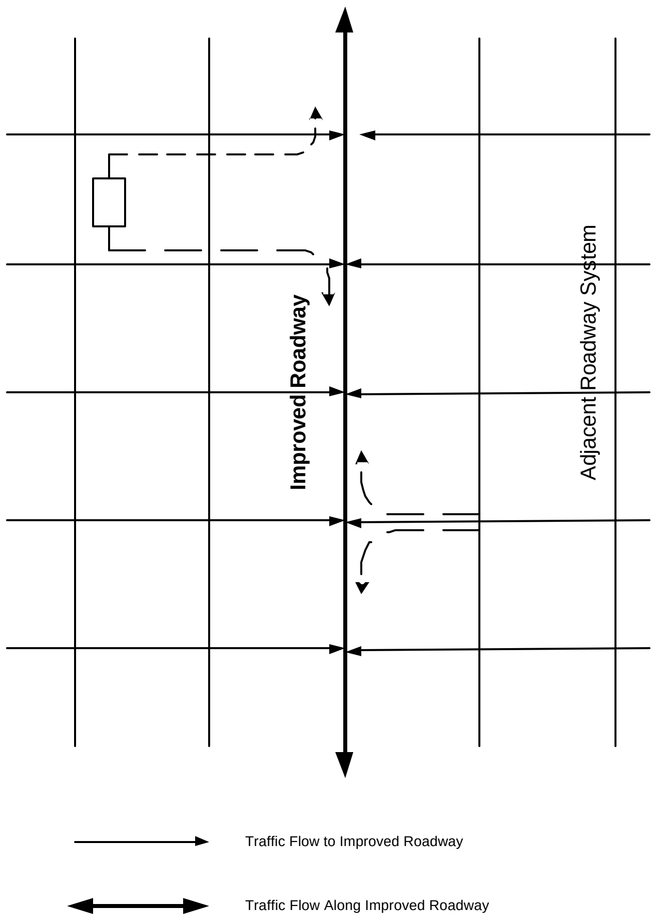


Figure 15. Traffic Redistribution[CCE15]

Paving an aggregate road may reduce traffic on the adjacent roadway system. Traffic is likely to be drawn to the improved (paved) roadway. The effect might be to reduce the maintenance requirements on the adjacent roadways. People may drive a few miles out of the way to travel on a paved road instead of an aggregate road, especially if the paved road takes them to their final destination. People will do this because they perceive their trip to be faster, cleaner, smoother, safer and a more pleasant experience. This perception may lead to an increase in the number of trips taken, leading to an increase in mobility. However, more fuel and other natural resources are used and more vehicle pollution is created with increased number of trips.

Increased Tax Base:

An increase in the tax base may occur if the corridor along the paved road is now perceived as a good location for development and for residential housing. If there is developmental growth along the corridor, the tax base is likely to increase and property will be assessed at a higher value. People prefer to live on a paved road, as is evident from the many requests a county receives to pave an aggregate road. The residents want the amenities of city life, such as smooth paved roads, but still enjoy the experience of living in the country. As a result of the desire to live along a paved road, the market value will be higher, and thus so should the assessed value of the property. The difference in assessed value is hard to quantify on a macro scale, but an analysis can be done quickly in a given locale. Although the increased tax assessment may not create a much larger tax base, it needs to be considered along with the potential for additional housing units being built because of the paved roadway facilities.

Economic Evaluation:

An economic evaluation is frequently conducted when comparing competing infrastructure improvements. Since the costs are accrued over several years, it is helpful to evaluate the costs and benefits for the alternatives at the same point in time. This is referred to as evaluating using equivalent single payments (present worth) or equivalent uniform series of payments. The following section will look at the present worth for ongoing gravel road maintenance and for providing HMA paving as was illustrated in Figures 13 and 14.

PRESENT WORTH EVALUATION

Whenever an infrastructure investment of the magnitude of paving a gravel road is considered, an economic evaluation is a prudent activity to pursue. Since the costs for the alternatives, ongoing gravel road maintenance and HMA paving, are accrued over several years, it is helpful to evaluate the costs and benefits for each alternative at the same point in time. For the analysis in this report, the year 2004 will be the reference point in time. This is often referred to as evaluating using equivalent single payments (present worth) or an equivalent uniform series of payments depending on whether a single expenditure/benefit is being evaluated or if it/they is/are a uniform series of expenditures/benefits. The present worth of the costs/benefits method combines all investments and costs and all annual expenses into a single present worth sum representing the sum necessary at time zero (2004) to finance the total disbursements over the analysis period. Of the alternatives compared, the one with the lowest present worth is considered the most economical. For this analysis the interest rate used is 4% and is compatible with government bonds and other government financing plans.

Cash Flow Diagrams:

Figures 16 and 17 are cash flow diagrams that illustrate the expenditures and benefits during the years that they occur. An upward pointing arrow indicates a positive value, normally the value of a benefit, and a downward pointing arrow indicated a negative value, which is normally an expenditure. The arrow lengths are not to scale but are relative to the value of the activity. The linear scale is the years and allow the costs/benefits to be viewed over a given period of time. In these figures the time period illustrated is 30 years.

Present Worth Calculations:

Following each figure is the present worth calculations for the scenario illustrated. The gravel road calculations are for ongoing gravel road maintenance activities that require re-graveling every five years (a five-year cycle), and for the average annual maintenance expenditures. The HMA calculations consist of HMA paving in year 10 with the ongoing maintenance activities, including a seal coat every seven years (7 year cycle) and the average annual maintenance expenditures.

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Terms:

The terms used in present worth calculations include:
F = future amount of money
P = present amount of money
r = interest rate (4 % is used in the calculations)
N = number of years
A = uniform series of payments

Formulas:

Single Payment:

$$P = \frac{F}{(1+r^N)} = F\ (pwf') \qquad (1)$$

Where pwf' is the present worth factor for a single payment as found in interest tables.

Uniform Annual Series:

$$P = \left[A \right] \left[\frac{(1=i)^N - 1}{i(1=i)^N} \right] = A(pwf) \qquad (2)$$

Where pwf is the present worth factor for a uniform series of payments as found in interest tables.

Mathematical Expressions:

The mathematical expressions used in the present worth calculation include the monetary amount, the factor being used, the interest rate and the number of years used. There are two expressions, one for single payment and one for an annual series. An example calculation for each expression is shown below. These examples are unrelated to the subsequent calculations.

Example 1: What is the present value of a $40,000 payment received at the end of the fifth year in the future?

Single Payment:
P = ($40,000)(pwf' – 4% - 5) (3)
= ($40,000)(0.8219) = $32,876
$40,000 is multiplied by the present worth factor for a single payment (pwf') at 4% interest for 5 years which is found in compound interest tables.

Example 2: What is the present value of five annual payments of $40,000 each made at the end of each year?

Annual Series:
P = ($40,000)(pwf – 4% - 5) (4)
= ($40,000)(4.452) = $178,080
$40,000 is multiplied by the present worth factor for a uniform series (pwf) at 4% interest for 5 years which is found in compound interest tables.

Gravel Road Maintenance

The gravel road maintenance expenditures are illustrated in Figure 16. The expenditures were developed in Table 5 and illustrated in Figure 9. There are annual grading and shaping expenditures of $1400 per year and every five years re-graveling is completed at the cost of $15,200.

Cash Flow Diagram:

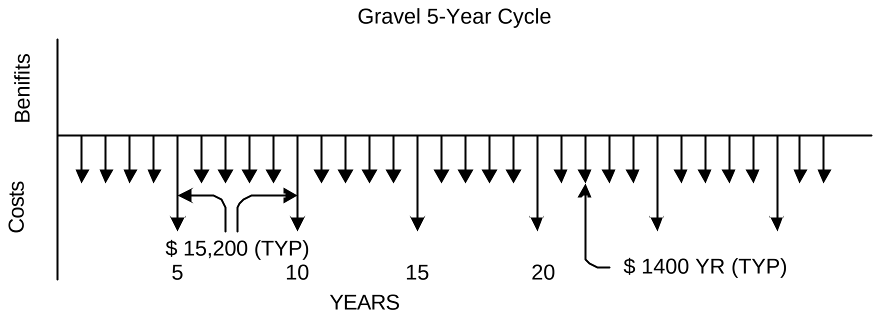

Figure 16 Annual Gravel Maintenance Cost Analysis – 5-Year Cycle

Present Worth Calculations:

The calculations for present worth of the expenditures shown in Figure 16 are presented in Table 7. The event that is occurring, the amount of the expenditure, the year(s) when the expenditure occurs, the factor used in the calculation, and the present worth value are shown.

Event	Cost	Year(s)	Expression	pwf	pwf'	P
Grading/Shaping	$1,400	1-4	(pwf-4%-4)	3.63		$5,082
Re-Graveling	$15,200		(pwf' -4%-5)	0.8219		$12,492.88
Grading/Shaping	$1,400	6-9	(pwf-4%-4)(pwf'-4%-6)	3.63	0.7903	$4,016
Re-Graveling	$15,200		(pwf' -4%-10)	0.6756		$10,269.12
Grading/Shaping	$1,400	11-14	(pwf-4%-4)(pwf'-4%-11)	3.63	0.6496	$3,301
Re-Graveling	$15,200		(pwf' -4%-15)	0.5553		$8,440.56
Grading/Shaping	$1,400	16-19	(pwf-4%-4)(pwf'-4%-16)	3.63	0.5339	$2,713
Re-Graveling	$15,200		(pwf' -4%-20)	0.4564		$6,937.28
Grading/Shaping	$1,400	21-24	(pwf-4%-4)(pwf'-4%-21)	3.63	0.4388	$2,230
Re-Graveling	$15,200		(pwf' -4%-25)	0.3751		$5,701.52
Grading/Shaping	$1,400	26-29	(pwf-4%-4)(pwf'-4%-26)	3.63	0.3601	$1,830
Re-Graveling	$15,200	30	(pwf' -4%-30)	0.3083		$4,686.16
					Total =	$67,700

Table 7. Present Worth – Gravel Road – Five Year Cycle

Note: Interest tables using four number values were used for the purpose of demonstrating the factors. More exact calculations can be made using calculators or computer programs.

HMA Resurfacing

The HMA resurfacing, annual maintenance, and seal coat maintenance expenditures are illustrated in Figure 17. The expenditures were developed in Table 6 and illustrated in Figure 11. Gravel maintenance activities occur during years 1 through 9. Then there is a HMA resurfacing cost of $131,600 per mile that occurs in year 10 and ongoing maintenance activities through year 30, except for years 17 and 24 when a seal coat application is applied.

Cash Flow Diagram:

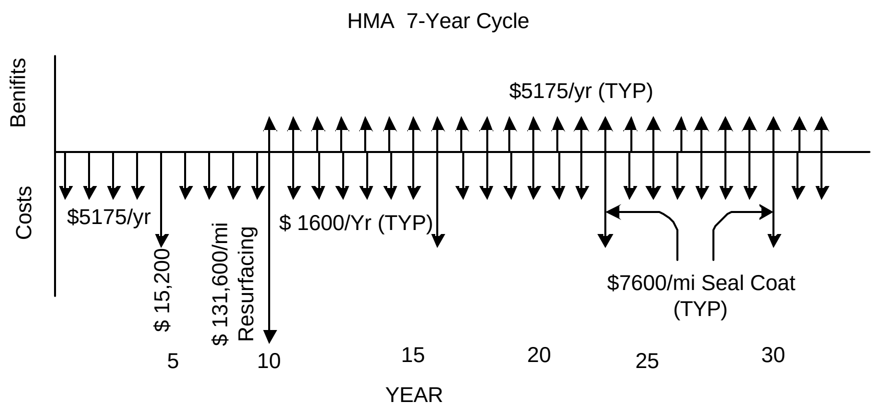

Figure 17. HMA Maintenance Cost Analyses – Seven-Year Cycle

Present Worth Calculations:

The calculations for present worth of the expenditures shown in Figure 17 are presented in Table 8. The event that is occurring, the amount of the expenditure, the year(s) when the expenditure occurs, the factor used in the calculation, and the present worth value are shown. There is a savings from not having to do the gravel road maintenance and that savings is shown in the gravel event calculation. The net present worth of $60, 996 is the difference between the HMA and the gravel expenditures.

Event	Cost	Year(s)	Expression	pwf	pwf'	P
Grading/Shaping	$1,400	1-4	(pwf-4%-4)	3.63		$5,082
Re-Graveling	$15,200		(pwf' -4%-5)	0.8219		12,493
Grading/Shaping	$1,400	6-9	(pwf-4%-4)(pwf'-4%-6)	3.63	0.7903	4,016
Resurfacing	$131,600	10	(pwf' -4%-10)		0.6756	88,909
Maintenance	$1,600	11-16	(pwf-4%-6)(pwf'' -4%-11)	5.242	0.6496	5,448
Seal Coat	$7,600	17	(pwf' -4%-17)		0.5134	3,902
Maintenance	$1,600	18-23	(pwf-4%-6)(pwf'' -4%-18)	5.242	0.4936	4,140
Seal Coat	$7,600	24	(pwf' -4%-24)		0.3901	2,965
Maintenance	$1,600	25-30	(pwf-4%-6)(pwf'' -4%-25)	5.242	0.3751	3,146
					Sub Total	$ 130,101
Gravel	$4,160	10-30	(pwf-4%-20)(pwf'-4%-10)	13.59	0.6756	$ 38,195
			Net Present Worth (Difference)			$ 91,906

Table 8. Present Worth – HMA – Seven-Year Cycle

Note: Interest tables using 4 number values were used for the purpose of demonstrating the factors. More exact calculations can be made using calculators or computer programs.

Present Worth Conclusion:

Calculating the present value of future expenditures for the purpose of comparing infrastructure improvements is a worthwhile effort. In this research, the present value of maintaining a gravel road was calculated along with the present value of improving the gravel road, with HMA paving, in year 10 of the analysis. Interest tables using four places to the right of the decimal point were used for the purpose of demonstrating the factors. More exact calculations can be made using calculators or computer programs. The expectation is the initial cost of the HMA paving is so large it will dominate the present value calculations and drive decision makers to make other decisions relative to roadway improvements. But that may not be totally true.

The net present worth of gravel road maintenance over a 30 year period was calculated to be approximately $68,000. This is the amount of funding that would need to be set aside today, at an interest rate of 4%, to meet the expenditures assumed for the next 30 years. The HMA paving option present worth over a 30 year period was calculated to be approximately $92,000. If the decision was made to follow the scenario developed within this research paper, the road would begin as a gravel road with a five-year cycle of re-graveling, would be paved with HMA in year 10, and would then have routine HMA maintenance and a seal coat application every seven years through year 30; then there would need to be an additional $15,000 per mile invested. If a 10-mile section of roadway is being considered, $150,000 would be required to make the future investments.

This is difficult to do when there is so much competition for resources, unless some of the other benefits discussed earlier are considered. The benefits that might be considered include changes in the maintenance activities required, a reduction in dust generated by vehicles, a smoother and safer pavement surface, improved vehicle and driver efficiency, redistribution of traffic, and a potential for an increased tax base. Some of these benefits will result in a direct impact on county budgets while others will have an indirect affect.

SUMMARY AND CONCLUSIONS

Traffic volumes and the expectations of neighboring land owners and road users are increasing for gravel roads in Minnesota. Interviews with state and local officials reveal a number of reasons for this increase, including:

- An increasing population on the urban fringe as former urban residents build houses in the rural areas surrounding urban areas
- An increase in the number of houses and cabins near lakes and other desirable natural features
- Increased traffic accessing recreation areas
- Increased number of trips by traditional rural residents

Many road users and neighboring land owners are current or former urban resident that have expectations of the level of service provided by paved roads. As a result of these increasing expectations, city, county, and township officials are being encouraged to upgrade the road surface. Given budgetary constraints, it is a challenge to upgrade such roads. Thus the decision of whether or not to upgrade must be carefully considered.

The cost of road maintenance and the cost of the upgrade are necessary inputs for the decision. It is generally understood that the cost of maintaining a gravel road increases with the traffic volume. As traffic volume increases, the road becomes rougher more quickly and this necessitates more frequent surface smoothing with road graders. Also, more gravel is thrown off the road or blown away as dust, necessitating more gravel replacement. One argument for upgrading aggregate roads is the potential savings from lower maintenance costs. However, this must be balanced against the investment required for the upgrade.

Interviews with local officials indicate that there is wide agreement on the investment costs required for typical upgrades. However, scant information exists regarding the cost to maintain gravel roads in comparison to paved roads. Also, little information exists on decision processes for deciding whether or not to upgrade a gravel road.

For Minnesota counties, the state aid report that is submitted annually by each county is potentially an excellent source of maintenance cost information. The level of detail varies widely from county to county; however, investigators found that several counties are reporting at a level of detail that is useful for this purpose. Four counties were selected for detailed analysis and efforts were made to select counties that are representative of those in the entire state. Several conclusions may be drawn from the analysis:

- Costs vary considerably from county to county.
- The proportion of roads that are currently paved increases with traffic category. In the category of 150 to 199 vehicles per day, more than half the roads are paved.
- Definitive cost comparisons between high-volume gravel and bituminous roads with the same traffic level are difficult because there are few segments of high-volume gravel roads to be included in the comparison and inconsistency of the data would cause results to be suspect.

- The historical costs to maintain both gravel and bituminous roads were between $1500 and $2500 per mile. Gravel road maintenance costs tended to be at the higher end of the range in categories where several road segments existed for comparison.
- Review of the database gives indications of errors with cost categories being mis-assigned.

A cost estimate based on estimated labor and equipment hours to perform typical gravel road maintenance tasks indicates that these historical costs may underestimate gravel road maintenance costs, especially for roads with high traffic volumes.

An economic analysis was conducted to determine if the typical investment necessary to upgrade a gravel road to an HMA road can be justified by the amount of money saved with the lower maintenance costs afforded by an HMA surface. The analysis showed that the maintenance savings alone could not justify the investment in the HMA upgrade. However this does not preclude the possibility that the upgrade could be justified to improve the quality of life for neighbors and the safety of road users and to encourage economic development for the local area, with reduced maintenance cost providing added benefit. Also, in some cases, an upgrade investment might be justified by maintenance savings alone when the road is upgraded to a lightly-surfaced road, such as seal coat. Lightly surfaced roads require a smaller investment in comparison to an HMA surface.

Paved roads provide improvements over gravel roads in several ways that cannot easily be assigned monetary values.

- Improved winter surfaces because often snow and ice can be completely scraped from the road surface (offset by higher snow removal costs)
- Improved safety from improved signage and delineation (offset by higher costs for signage and delineation)
- Surfaces with higher skid resistance (offset by higher vehicle speeds)
- Smoother surfaces that increase road user satisfaction and reduce vehicle maintenance costs
- Reduction in fugitive dust emissions
- Improved vehicle and driver efficiency that reduces fuel costs and driver fatigue
- Redistribution of traffic away from other gravel roads (reducing maintenance requirement) as road users preferentially select paved roads
- Increased tax base as real-estate next to paved (but formerly gravel) roads increases in value and development increases (offset by problems that typically occur when rural areas are developed)

Note that in many cases the benefits, including certain cost savings, do not directly result in an increase in funding available for road improvements. Vehicle maintenance savings is an example of this. This can cause a dilemma where certain parties may benefit greatly from the improvement, possibly enough to justify the investment. Yet the agency may not have the funding available to make the investment.

RECOMMENDATIONS

Based on the aforementioned conclusions, recommendations may be made. Because the majority of the roads having traffic over 200 vehicles per day are paved, it is recommended that serious consideration be given to upgrading roads with that traffic volume. This assumes that current officials in the four counties subjected to detailed analysis are making proper decisions given current funding and the non-monetary benefits that accrue from the upgrade. Although the necessary investment cannot be justified only on the savings in maintenance costs between paved and gravel roads, past experience has shown that this is a satisfactory decision point. Anecdotal evidence suggests that most government agencies have been able to finance improvements when traffic has reached these levels.

Cost estimates developed as part of this project suggest that the historical costs may underestimate the actual cost of maintenance. Note that when the road with higher traffic is upgraded, a larger number of road users will reap benefits that are difficult to quantify and neighboring land owners who are most acutely negatively impacted by unpaved roads will gain improvements, with possible increases in property values with attendant increases in property tax collection.

Since the effort to include a gravel road upgrade into a construction program often takes several years and since there is a general trend of increasing traffic volume, especially in urban fringe areas, it seems reasonable to commence planning for the upgrade when traffic volumes reach 100 vehicles per day.

The annual reports that counties submit to the state aid office are potentially a rich source of cost data that could be used to improve decision making. It would be desirable to investigate methods for standardizing data collection and reporting as well as improving the accuracy of entering categories. In making improvements, care should be taken to not increase the administrative burden required in the reporting process, lest data quality suffer due to the excessive effort required to comply.

Considerable effort has been invested in this study to identify major issues, locate an excellent source of cost data, and learn how manipulate it to analyze the data. Additional effort could be justified to identify high-volume gravel roads, interview local officials to ascertain that costs are being properly recorded, and analyze a larger group that could serve as a point of comparison to bituminous roads with similar traffic volumes.

In this effort, central tendency was documented by calculating mean values and dispersion was documented by calculating variance. Further investigation has shown that it is likely that most of the data is not normally distributed. Therefore, the results of the analysis would be more useful if central tendencies were documented by calculating the median and dispersion was documented by giving high and low percentiles.

Additional information could be garnered by reviewing the data looking for unusually high- or low-cost roads and then following up with interviews to document the cause of the high or low costs.

It is further recommended that local officials consider developing their own cost estimates for gravel road maintenance operations and check them against their historical data. In cases where officials are confident of their cost calculations, they may be advised to use the estimate in place of the historical costs.

Upgrading a gravel road to an HMA surface should be considered an investment that will primarily reap rewards that do not result in a monetary savings to the government agency. Neighbors and road users will benefit in ways that will improve their quality of life; economic development may follow better living conditions resulting in some increase in property tax collection. Local officials may use the cost estimating and analysis techniques described in this report to help them target investments toward roads that will provide the best result.

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APPENDIX A

Annotated Bibliography

Greg Johnson

(A Comparison of the Life-Cycle Costs of Asphalt Concrete and Portland Cement Concrete Pavements in Olmsted County, Minnesota) by Rebecca Embacher

- Comparison of similar age, geometry, structural characteristics, condition, traffic, and rehabilitation. *When I try to compare aggregate road upgrades. I will have to try to hold as many of these factors as possible constant.*
- Only included initial construction costs above the finished grade. *This may be an issue with my study since the roads may need a regrade to bring up to higher standards.*
- Cost indices were used to convert into equivalent "constant dollars" Used the Means Heavy Construction Historical Cost Index.
- Used nest present cost and uniform annual cost
- Analysis period needs to be determined

Transportation Research Record 702 – Low-Volume Roads: Second International Conference,
p. 83 Optimal Timing for Paving Low-Volume Gravel Roads by Anil s. Bhandar, University of Dar-es-Salam and Kumares C. Sinha, Purdue University

- Use a break-even analysis (minimum volume above which the next present value of paving is in excess of zero)
- If other opportunities are competing, then to when the net present value is maximized

COST 337: Unbound Granular Materials for Road Pavements

- There needs to be a test for resistance to permanent deformation
- A different mindset is need for the design from "where can I find an aggregate to meet my need (?); to: "how can I beneficially use this available aggregate to successfully build a road pavement to a required standard (?)"
- "The mechanical behavior of unbound granular material, as used in road construction, must be considered under three headings: strength, stiffness, and permanent deformation behavior"

This report is a useful summary of all the different standards that are being used by European countries for the design of the base/subgrade layers. Included are recommendations for testing and further research.

"*Cost Effectiveness of Selected Roadway Dust Control Methods for the Mendenhall Valley, Juneau, Alaska*" *by Matthew Reckard (Alaska DOT&PF Research Section, 1988)*

Decision making based on construction costs and results measured from a previous study the correlated PM10 to different road surfaces. Discussed that emissions need to be measured when comparing dust control measures. This report had a very narrow scope and made many assumptions.

"*Evaluation of Selected Dust Palliatives on Secondary Highways*" *by R. W. Mulholland (Saskatchewan Department of Highways – Technical report 18, 1972)*

- *Calcium Chloride provided the best combination of ease of construction and performance, but it cannot be relied upon for a second season.*
- *Table 1 – Scale of Dust Condition Rating,* Subjective, but good

The report compared CaCl2, NaCl2, and emulsion. A very extensive test with empirical results.

"Economic Disbenefits of Dust from Unsealed Roads" by Works Consultancy Services, LTD, Wellington, New Zealand. Transit New Zealand Research Report No. 16, 1993.

- *Hoover reported (1981 Iowa report) that the surface aggregate with appropriated particle size distribution could reduce wear to low levels. This would reduce maintenance and regraveling costs. (Hoover, J.M. 1981. Final report: Mission-oriented dust control and surface improvement processes for unpaved roads. Department of Civil Engineering, Iowa State University. Iowa Department of Transportation Project HR-194.)*

This report is a literature review of topics relating to the effects and cost of dust due to gravel roads. There is little hard fact numbers for analysis. The effects would be affected by local characteristics.

"*The Development of Performance Related Material Specifications and the Role of Dust Palliatives in the Upgrading of Unpaved Roads*" *by David Jones and Philip Paige-Green, Road Development and Environment Technology, Division of Roads and Transport Technology, CSIR, 1996?.*

- *"Although the correct selection of materials will often improve driving conditions on the road and living conditions adjacent to the road, dust levels may still be unacceptable."*
- *Recommended Material Specifications for Unpaved Roads (Table II)*
- *The author could find no improvement by incorporating climate and traffic.*

- *It is important to have good construction practices and 4% cross-slope.*
- *Jones (1995) found that silt content, plasticity characteristics, hardness and relative density, velocity of wind were the key component to dust generation.*
- *Figure 1, Relationship between shrinkage product and grading coefficient could* this be applied to Minnesota?

This is report, the author; investigated 100+ road sections to determine what surface aggregates had the best performance. It then gives new specifications for future construction. It then explains how the addition of dust control products will work with different aggregate characteristics. The road user costs were calculated by using the HDM-3 model.

"Economic Evaluation of Pavement Design Alternatives for Low-Volume Roads" by David R. Luhr and B. Frank McCullough as printed in Transportation Research Record 898.- Proceedings to 3rd International Conference on Low-Volume Roads

- *Use a computer program (pavement management system) called Pavement Design and Management System (PDMS) for analysis*
- *For their conditions, aggregate surface < 5 ESALs/day, surface treatment 5 to 20 ESALs/day, and HMA for > 20 ESALs/day.*
- *Computer program uses initial construction, maintenance, rehabilitation, user costs, and salvage cost.*
- *Used 20 year analysis period*
- *Used assumed values for all examples and discussions*
- *Looked at total cost and marginal cost (due to different vehicle types)*

This report is very close to the end product of what this research project should look like. Unfortunately, they used a computer model to predict scenarios, instead of actual data.

"Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT <=400)" by American Association of State Highway And Transportation Officials (AASHTO), 2001.

This is a less restrictive geometric standard for low-volume *local* roads. This is based on risk assessment on these types of roads. Gives all the geometric standards and many examples.

"When to Pave a Gravel Road" by Kentucky Transportation Center, April 1988.

- *"There is nothing wrong with a good gravel road. Properly maintained, a gravel road can serve general traffic adequately for many years."*
- *Need to answer 10 questions*
  1. *After developing a road management program (Needs, priorities, short/long term plan)*
  2. *When the local agency is committed to effective management ("Building roads to last requires an attitude of excellence.")*

3. *When traffic demands it*
    a. *ADT*
    b. *types of traffic*
    c. *functional importance*
4. *After standards have been adopted*
    a. *design and construction standards*
    b. *maintenance standards*
5. *After considering safety and design*
    a. *a paved road needs higher geometric standards*
6. *After the base and drainage are improved*
    a. *the road is only as good as the foundation it rides on*
7. *After determining the costs of road preparation*
    a. *total road costs*
    b. *maintenance costs*
8. *After comparing pavement costs, pavement life and maintenance costs*
    a. *determine a cost/mile/year for different scenarios.*
9. *After comparing user costs*
    a. *User cost factors from AASHTO can be used*
10. *After weighing public opinions*

Very useful document to give planning direction and all the components that go into making the decision.

"Economic Aspects of High Speed Gravel Roads" by M. K. Reckard (Alaska Dept. of Transportation and Public Facilities, Fairbanks) March 1983. Report No. FHWA-AK-RD-83-20.

- *"At the present time the same basic design process is followed for nearly all state road projects in Alaska. One of the underlying assumptions of this process is that all roads may eventually be paved and the designs are developed to accommodated this…This design procedure may not be the best practice for roads which are not expected to be paved for two basic reasons; first, it may lead to unnecessary costs in road construction, and second, it may not produce the best gravel-surfaced road."*
- *Gravel surfaces may be a practical alternative to HMA road.*
- *Gravel roads may provide superior performance in areas of poor subgrade strength because repairs can be made easily.*
- *"The use of dust control agents on high speed unpaved roads, although costly, is almost mandatory to ensure a high level of performance."*
- *Appendix C shows units costs for reconstruction and maintenance, and then tables are broken out by subgrade strength (good to poor).*

This report shows that a paved road is not necessarily the most cost effective, if the subgrade strength is poor or variable. Assumed values are used for most of the discussion, but is check with some actual data. On a good subgrade a paved road is more economical. Most of the differences in costs are due to subgrade strength and associated maintenance costs.

"<u>Towards Successful SPP Treatment of Local Materials for Road Building</u>" by P. Paige-Green and K. Coetser (Division of Roads and Transport Technology, CSIR, P.O. Box 395, Pretoria, South Africa) April 1996.

- *Current design recommendations do not adequately address traffic volumes < 200 vpd.*
- *"The main parameter of Critical importance in any construction material is the influence of moisture on the strength properties."*
- *Standard engineering tests do not characterize the properties of these soil stabilizers.*
- *Ion exchange was the principle mechanism by which SPP improve soil*
- *Construction methods and quality control are critical to success.*
- *This report focused on sulphonated petroleum products (SPP)*
- *Tests of the material that the SPP will be added needs to be done beforehand to determine if and how they can be used best.*

This report gives details of the different type of clays and they interact with each other, water, and stabilizers. Some clay types will work better than others. X-ray diffraction to PI needs to be complete to determine the best use and appropriate concentrations.

"<u>Canadian Practice in the Design, Use and Application of Bituminous Surface Treatments</u>" by J. L. M. Scott (GE Ground Engineering Ltd.) February 1990, reprinted July 1995.

- *A double seal produces less defects than a single seal*
- *Saskatchewan does not apply spring load restrictions to their sealed granular bases.*
- *Most used high float emulsions with graded aggregates.*
- *Double High Float seal ~$1.85/m^2*
- *Over a granular base, seals lasted from 5 to 15 years.*
- *Surface treatments can be used as a replacement to HMA.*
- *Surface treatments can be used in higher traffic situation than what they are generally thought.*
- *Treat/Pave driving lane and shoulder to minimize premature edge defects.*

A summary of the extent and details of the use of surface treatments in Canada. Shows that design and construction techniques can be more of an art than a science. Tables show reasons why different defect occur. Application rates are quite variable.

"Optimal Use of Marginal Aggregates for Achieving Cost Effective Surfacing on Low-Volume Roads in Developing Countries" by M. I. Pinard and B. O. Obika, Botswana Roads Department, as presented at 1997 Xiiith IRF World Meeting, Toronto, Ontario, Canada, in the Low-Volume Roads Session.

- *Otta seal was originally developed as a temporary surfacing for newly constructed roads.*
- *Material with high crushing strength is desirable.*
- *> 100 vpd = open graded aggregate preferred*
- *< 100 vpd = dense graded aggregate preferred*
- *soft binders are required*
- *primers may be necessary between a fine graded base and a dense graded aggregate otta seal*
- *there is no current design method for otta seal (empirical)*
- *the most durable and expensive option is the dense graded, double Otta Seal*
- *"the more rolling that is applied to the Otta Seal the better will be the quality of the end product" This means opening the road to traffic immediately after rolling is completed.*
- *Minimum of 2 month between construction of layers*
- *"A rule of thumb is to assume that a good result has been achieved when the bitumen can seen being pressed up in-between the aggregates, sparsely distributed in the wheel tracks of the chip spreader."*
- *Advantage of Otta Seal is good performance with "inferior aggregate"*
- *Disadvantage of Otta Seal is difficulty specifying requirements for quantities for bidding*
- *In Botswana Otta Seals cost 20% less than conventional seals.*
- *Otta Seal favored when 1. Construction in remote areas 2. Marginal workmanship 3. Flexibility and durability is required on the base 4. Low maintenance required 5. High weathering areas*
- *Double graded seal = 10 to 12 years of life*

This report gives a good overview of Otta Seals with their strengths and weaknesses. The authors prefer open graded aggregates to dense graded aggregates, which is different than the original "design" from Norway. Points out that the design is very empirical.

"Bituminous Surface Treatments" by Sue Niezgoda, Maureen Kestler, and Alan Yamada file: http://www.transportation2000.com/preceedings/Materials%20ii/Paper-Niezgoda-Kestler.doc.

- *Paper deals with surface treatments over existing HMA roads.*
- *Define high-volume > 5000 ADT, low-volume < 5000 ADT*

Paper addresses surface treatments over HMA and summarizes literature to determine conclusions.

"A Comparison of the Life-Cycle Costs of Asphalt Concrete and Portland Cement Concrete Pavements in Olmsted County, Minnesota" – by Rebecca Embacher and Mark Snyder.

- *All agency costs over the life to the pavement need to be put into the economic analysis, not just initial costs. p. 1*
- *There needs to be objective assessments of true agency costs. p. 1*
- *Initial costs and a complete history of maintenance and rehabilitation are required. p.2*
- *Did a comparison on similar dates of construction, traffic volume and mix and projects lasted at least 10 years. p.2*
- *Broke roads into the following subcategories. 1) pavement type 2) time since construction 3) geometry 4) structural characteristics 5) present condition 6) traffic characteristics. P.6*
- *Initial construction costs were taken from assigned SAP numbers. Use "certified to date" quantities of materials p.8*
- *Cost analysis was done above the finished grade*
- *Excluded approaches and drives p. 10*
- Were the bases equal thick nesses or did they vary by surfacing type
- *Distributed initial construction costs over uniform sections p.12*
- *Adjusted and distributed mobilization costs p.13*
- *Cost analysis ledgers p.13*
- *Maintenance costs p.16*
- *Used labor cost X 37.38% fringe benefit rate – county supplied p.17*
- *Maintenance material costs were based on percentage of labor costs (maintenance engineer supplied) p.18*
- *Backdated and forecasted maintenance costs over the life of the project p. 19*
- *Determined a graph (figure 5) on effect of time on cumulative maintenance costs p. 20*
- *Determined striping costs p. 22*
- *Determined traffic volumes p.25*
- *Salvage year (would require major rehabilitation or reconstruction) p.27*
- *Excluded the following items 1) common labors 2) grader/scraper/dozer 3) Bit. Mix production (common patching) 4) painting crossings 5) pneumatic roller (subgrade) 6) dust treatments 7) Engineers 8) shouldering items*
- *Used the Means Heavy Construction Historical Cost Index as index for the project.*
- *MnDOT's estimating unit provided indices for excavation, structures, and surfacing*
- *Used a combination of Means Heavy Construction Historical Cost Index and MnDOT's Surfacing Indices*
- *Public agencies incur only costs and do not derive benefits p.33*
- *Used net present cost and equivalent uniform annual cost p.33*
- *NPR converts all cost into equivalent values of today's currency (over the life of the project) and sums them to provide a single cost p.34 (equation)*
- *EUAC is used when comparisons are made between alternatives with different lives p.35*
- *"The EUAC is the value of a cost incurred annually over the life of the project that yields the same present worth of costs (considering changes in the value of money over time) as the actual expenses at the times they are incurred." P.35*

- *Used capital recovery factor (equation) to determine EUAC p.35*
- *NPC and EUAC were normalized for traffic volume*
- *Table I-1 Means heavy construction Historical Cost Indices*
- *Table I-2 MnDOT Construction Surfacing Indices*

"<u>Cost Effective Methods to Upgrade Unpaved Roads Phase I and Phase II</u>" by Robin Sukley, Pennsylvania Department of Transportation, Bureau of Construction and Materials Engineering Technology and Information Division, Final Report, Research Project No. 91/92-069, July 1999.

- *Objective was to evaluate cost effective methods and performance of treatment methods to upgrade existing aggregate roads. The comparison will be against a bituminous seal coat (with and without primer).*
- *Cost data show is for the entire length of road, and not just for the treatment area. Therefore, the costs may be misleading.*
- *Primer and Single Bituminous Surface (SBS) Treatment placed on existing roadway (control), this is the standard maintenance treatment with a life of 1 to 3 years.*
- *Cold mix in-place recycling with a SBS treatment on existing roadway, did not perform in 2 of 3 locations.*
- *RAP with SBS treatment on existing road, performance satisfactory on one road, and marginal on another.*
- *Primer and FB-2 Bituminous wearing course over existing roadway, only one road tested, but performed well (#2)*
- *Primer and FB-1 Bituminous binder course with SBS treatment on existing road. Only tested on one road, but had satisfactory performance. (#5)*
- *SBS over existing road, control, year 2, standard practice, poor performance*
- *Cold in place recycling with a SBS treatment on existing roadway with the use of Perma-zyme performed satisfactory, TerraZyme performed satisfactory (#4)*
- *FB-1 Bituminous Leveling Course with a SBS treatment on existing roadway, had good performance*
- *Cold mix in place recycling, FB-1 bituminous leveling course with SBS treatment on existing road, good performance (#1)*
- *FB-2 modified bituminous wearing course applied as a wearing surface on existing road, good performance >= 3 inches, 2 inch section had problems (#3)*
- *FB-2 bituminous wearing course with a single bituminous seal coat treatment on existing roadway, minor problems, good performance (#6)*
- *# are ranked by from most reliable and cost background*

There is no determination of what would be most cost effective. The sections were just compared against the performance and maintenance done on the control section. There was no cost comparison of performance versus initial construction costs for each treatment. The report does show that treatment work differently in different counties.

"Guidelines for Cost Effective use and Application of Dust Palliatives" by UMA Engineering Ltd., 1987. Published by Roads and Transportation Association of Canada, 1765 St. Laurent Blvd., Ottawa, Canada, K1G 3V4.

- *Adoption of dust control program is dependant on the scope of the social and environmental impacts, classification of road, and traffic.*
- *Use 500 ADT as cutoff for a single year treatment of a dust control product*
- *Roadway geometrics should be reviewed, because a better driving surface will cause drivers to increase their speed.*
- *Percentage of fines in surfacing aggregate should be between 10 and 25% pass #200 sieve.*
- *Figure 1.2 is a product selection chart based on traffic volumes, subgrade type, %#200, climate, and environmental impacts*
- *There are tangible and intangible benefits to a dust control program*
- *All programs need a road with adequate base and subgrade*

Very useful report on summarizing the work that has been done historically and is currently being done in Canada. Report does not give exact values for products or procedures. Does explain well all the details of a gravel road.

"A Manual on User Benefit Analysis of Highway and Bus Transit Improvements" for user costs.
Need to determine how to calculate user costs.

"Life Cycle Cost Analysis in Pavement Design" by James Walls III and Michael Smith, Federal Highway Adminstration, Pavement Division, HNG-40, Office of Engineering, Federal Highway Administration, 400 7th Street SW, Washington, DC 20590, Publication Number FHWA-SA-98-061, March 1998, Draft Report.

- *Recommended a 35 year analysis period*
- *Used a discount rate of 4%*
- *Included accident and work zone costs*
- *This report was to show how to predict into the future. All numbers were estimates or projections*
- *Recommended doing a sensitivity analysis*
- *Recommended a risk analysis*

"Graded Gravel Seal (Otta Seal" by Torkild Thurmann-Moe and Hans Ruistuen, Published in 3rd International Conference on Low-Volume Roads. Transportation Research Record 898, 1983.

- *Developed in Norway between 1963-1966.*
- *Norwegian report*
- *Cost*

Annual maintenance on gravel roads 0.4 to 0.7 $/m^2
Otta Surfacing
Single layer 1 to 1.5 $/m^2
Double layer 2-3 $/m^2
Oil gravel cold plant mix (100 kg/m^2) 3.5 to 5 $/m^2
Asphalt concrete (90 kg/m^2) 6-7 $/m^2

Literature Review for LRRB 769

Jacob Thorius

National Association of County Engineers (NACE). (2003). "Ten Essentials of a Good Road." Washington, D.C.

- Keep water away from road
  - Drainage cannot be overemphasized in road construction and maintenance
  - Too much water in base material weakens road
  - Water allowed to remain on top of a road weakens the surface and combined with traffic, causes potholes and cracking
  - Proper surface drainage prevents water from infiltrating the pavement surface and removes water from the driving lanes to the ditches which carry water away
  - Surface drainage system has four main components: road crown, shoulders, ditches, and culverts
    - Road crown or superelevation of road surface drains water off the road surface
    - Shoulders are extension of road surface and allow for continued flow of water to ditches
    - Ditches carry water away from roadway – need to be kept clean and protected from erosion, water left in ditch can leak back into base
    - Culverts channel water from one side of road to the other – help control flow of water and slow it down to reduce erosion
- Build on firm foundation/compact soils well
  - Road wears out from the top down, but falls apart from the bottom up
  - Base supports everything above it – needs to be a stable foundation made of stable material
  - Adequate moisture is needed during the compaction process
  - Future traffic loads or changes in moisture content can cause settling and failure of improperly compacted soils
  - Well-graded soils compact easier and crushed or angular particles compact to more stable condition
- Use best soils available
  - Quality of soils used depends on budget and availability; consider long-term consequences of using lower quality material.

- Use of inferior base material may require excessive maintenance during road's life and expensive rehabilitation
- Build for traffic loads and volumes
  - Design roads with expected traffic type and volume in mind – design to accommodate the largest vehicle to use road under normal conditions or for the largest piece of equipment to maintain road
  - Obtain guidance from state DOTs about type and thickness of pavement to use.
  - Low-volume roads with some truck traffic provide good service with "chip or sand seals" – increases in traffic may be better served with cold- or hot-mix asphalt
- Pave only roads that are ready
- Build from bottom up
  - Before doing anything to surface, need to consider what may be causing the problem underneath – poor drainage, insufficient base material or thickness
- Protect investment with regular road maintenance activities
- Keep good records to formulate budgets and help in future decisions on which actions should take place.

Swift, L. W., Jr. and Burns, R. G. (1999). "The Three Rs of Roads." Journal of Forestry, August, 40-44.

Talks about maintaining forest roads to minimize the amount and velocity of water and sediment runoff into surround waterways.

- Roads classified by use level and physical condition
  - Arterial or collector roads – form connecting transportation network that carries higher volumes of traffic, usually two-lane roads with all weather gravel surface
  - Local roads – generally single lane graveled or dirt roads that carry lower volumes of traffic
- Need to eliminate/minimize direct flow of runoff in to nearby streams, either divert runoff to sediment traps or reduce volume of water in one area, which reduces sediment capacity and is easier to control

Evans, L. D. (1995) "Low-Volume Road Geometric Design Practices in the National Forests of the United States." *Conference Proceedings,* International Symposium on Highway Geometric Design Practices, August 30 - September 1, 1995, Boston, Massachusetts, Published electronically as EC003 by Transportation Research Board, Washington, D.C., http://gulliver.trb.org/publications/circulars/ec003/ch42.pdf

Since each road is unique, the geometric design practices used for the low-volume road need to be selected based on the function of the road, traffic volume, vehicle size, safety and environmental issues, and desired speed. The success of low-volume road designs is dependent on engineering flexibility and judgment since low-volume roads function differently than major roads. Accepted geometric design policies and guidelines provided by AASHTO are modified as needed to fit the unique needs of each road. This flexibility allows for design of low-volume road at an economical cost.

Smadi, A., Hough, J., Schulz, L., and Birst, S. (1999). "North Dakota Gravel Road Management: Alternative Strategies." Transportation Research Record, 1652, 16-23.

Major gravel road users: farmers, mail carriers, rural residents, school busses. Need quality gravel roads to allow for acceptable mobility by the users. Farming equipment and related vehicles for support of farming operations are getting heavier, thus placing more demand on a gravel road's structural, operational, and safety aspects. Rural road users are more dependent on urban areas/services and thus need roads with more urban characteristics (at least want an improved road surface – more gravel, paved, wider road w/ shoulders, and improved/wider bridges). Tight budgets make it hard for county to improve/maintain their road network. Tight budgets are a result of cost cutting passed down from national and state funding levels, population shifts, and poor economic activity within the county. Supplies of quality and affordable gravel are running thin. Hauling of gravel over long distances is uneconomical because of high transportation costs and wear and tear on roads and trucks used for shipping process. Level of maintenance of gravel roads varies greatly with traffic levels, county policies and practices, and available resources. Paving a road is one option to reduce the maintenance costs of a gravel road; however, many times the initial construction costs make it hard to justify the upgrade. Only once user and other opportunity costs are considered does it become justifiable to pave the gravel road. Even though paving the road has been justified, the county may still not have the funds to pay the initial investment required to pave the road. Another option for improving the road quality without paving is with the use of chemical additives to control dust and stabilize the road; however the success of their use with different soil types, climates, and traffic volumes varies. Use of soil testing improves success of additive usage. The most widely used additive is a chloride additive, then a clay additive, and finally either bituminous binders or another adhesive are used. Not only do additives reduce maintenance costs with the stabilized and dust free road, but they also improve safety, reduce vehicle maintenance and pollution, and improve overall perceptions by the public of the road condition. More attention needs to be paid to better and accurate record keeping supporting future decisions; data kept needs to be consistent from year to year and county to county. Need for guidelines or standards on gravel road performance and maintenance practices, similar to those for pavements.

Luhr, D. R., and McCullough, B. F. (1983). "Economic Evaluation of Pavement Design Alternatives for Low-Volume Roads." Transportation Research Record, 898, 24-29.

Low-volume roads make up a vast majority of the road network, which leads to a large annual investment for building and maintenance despite the relatively low cost/mile. Pavement design is important for low-volume roads because total pavement costs for low-volume roads are more sensitive to pavement design than costs for highways. Thus designers need to be sure to determine the optimum pavement design and rehabilitation strategy for each road, which is made easier through the use of a pavement management system. Forest Service and the University of Texas at Austin developed Pavement Design and Management System, a pavement management system.

Paper goes on to tell how computer program works and explores the economic consequences of certain pavement design alternatives with the use of the pavement management software. Has figures of total cost versus different traffic types and quantities of vehicles per day.

Nelson, J. D., Tymkowicz, S., and Callahan, M. (1994). "An Investigation of Emulsion Stabilized Limestone Screenings." Report No. HR-309, Iowa Department of Transportation, Ames, Iowa.

A report on the use of a limestone screenings/emulsion mix for use as a base capable of supporting local traffic. A Linn County, Iowa Road W56 was used for the test section, which was 1.27 miles long and constructed in 1988. An earlier Iowa State University laboratory study showed that waste limestone screenings could be used as the sole aggregate in an emulsified asphalt mix. Seven test sections were constructed of either 4 or 6 inch thicknesses and a residual asphalt content of 2.5%, 3.5% and 4.5% of the dry weight of the waste limestone aggregate, with one 6 inch thick section and 0.0% residual asphalt. The use of limestone screenings mixed with an asphalt emulsion as base is a viable technique. An acceptable base was produced with at least a 3.5% residual asphalt content and a depth of 4 inches. The 6 inch thickness produced a base yielding fewer cracks and a higher structural strength. For structural strength, the optimum residual asphalt content most likely resides near 3.5%. However, the results may vary as the gradation of the limestone screenings change, especially as the percentage of clay and silt particles increase.

The following conclusions were made

- A low maintenance roadway can be produced using a seal coat surface on 6 inches of stabilized limestone screenings with 4.5% asphalt cement.
- A 6 inch emulsion stabilized base with less than 3.5% asphalt cement does not produce a satisfactory low cost maintenance roadway
- A 4 inch emulsion stabilized base does not produce a satisfactory low cost maintenance roadway.
- A 2 inch asphalt concrete surface would be necessary on many roads to provide a low maintenance roadway using emulsion stabilized limestone screenings.

Hoover, J. M., Squier, L D., Solomon, P. L., and Handy, R. L. (1975). "Evaluation of Chemically Stabilized Secondary Roads – Linn County, Iowa." Report No. ISU-ERI-Ames-76202, Engineering Research Institute, Iowa State University, Ames, Iowa.

A second progress report on the "Evaluation of Chemically Stabilized Secondary Roads," in Linn County, Iowa. The first report contained information on the purpose, objectives, and phases of the project, construction, location and materials, post construction density and moisture contents, and limited Benkelman Beam and Spherical Bearing Value field tests. Several test sections were constructed with different treatment methods. As of the current phase of the research when this report was written, in general, performance of all field sections, materials and additives had not been as good nor as poor as initially expected.

Sullivan, J. (1996). "Pavement Recycling Executive Summary and Report." Report No. FHWA-SA-95-060, Federal Highway Administration, Washington, D.C.

This is a report on status of recycling asphalt pavements today. The report summarizes the current use, materials mix design, structural design, construction and performance of recycled HMA pavement. Some of the reports conclusions include:

- Use of RAP in HMA pavement is not widely accepted across the U.S.
- There are too many restrictions on the use of RAP for its use to be increased and many engineers feel it is second-rate to virgin HMA.
- Recycled HMA pavement performance will be comparable to regular HMA as long as proper design and control procedures are followed.

Some of the recommendations to increase the use of RAP include:

- States need to consider revising specifications to allow for RAP content based on a thorough mix design.
- Production sampling and testing programs need to be done to ensure a proper mix is being produced.
- More sampling of pavement to be used as RAP needs to be performed to ensure better indication of what is actually present.
- More training on the use, production, handling, and construction of HMA pavements with RAP needs to occur.

American Society of Civil Engineers (ASCE) Highway Division. (1992). "Local Low Volume Roads and Streets." Federal Highway Administration, U.S. Department of Transportation.

A manual that provides a collection of information on low-volume roads. Provides agencies with basic information concerning low-volume roads in an easy to use manual. Covers the following topics: planning, construction and maintenance, traffic and safety design, surface management, and geometric design considerations; and issues related to each of those topics.

Forsberg, A. T. (1997). "Blue Earth County Finn / Oil Gravel Project C.S.A.H. #24 from T.H. 30 to C.S.A.H. 25." Report No. MN/RC-97/12, Blue Earth County Public

Works Department, Mankato, Minnesota. Minnesota Department of Transportation.

A report on the use of Finn Road or Oil Gravel technology as a pavement surface in Blue Earth County, MN the may provide an economical, easy to maintain, and improved all-weather driving surface instead of a gravel road surface. Two test sections were constructed, one with a 50/50 mix of quartzite and natural gravel aggregate, in order to test the performance and costs of using the more expensive quartzite. The pavement consisted of an additional 7 inches of Mn/DOT class 5 base was added to the existing 3-5 inch gravel base. After trimming the base to a uniform thickness, the Finn Road mix was placed in one 2.5 inch lift. Had a segregation issue during construction, not sure where from, but possibly from multiple handling of mix or from not using a uniformly graded mix. Some conclusions from the project include:

- Pavement remained soft for several weeks after placement and thus susceptible to damage. However, by end of the summer the pavement did harden sufficiently to resist damage. No rutting damage occurred during this time.
- Went through one winter with no snowplow damage and appears to be in good shape.
- The Finn Road was about 33% less costly to construct than a traditional 7 ton bituminous pavement in Blue Earth County, MN. The pavement cost $112,000 per mile for 7 inches of additional base and 2.5 inches of pavement.
- As long as the Finn Road pavement is structurally able to accommodate the occasional heavy loads without failing, it should be more economical to maintain, resulting in reduced maintenance costs.
- The use of Finn Road pavement has the potential for future uses as long as segregation issue is addressed and after monitoring pavement performance for several years.

Lunsford, Lt. G. B., and Mahoney, J. P. (2001). "Dust Control on Low-Volume Roads: A Review of Techniques and Chemicals Used." Report No. FHWA-LT-01-002. Washington, D.C.: Federal Highway Administration, U.S. Department of Transportation.

Report provided a review of different dust control practices from around the world. Findings resulted in the following:

- Chloride family of dust suppressants generally easier to use, have the greatest combination of ease of use, durability, and cost while controlling dust in temperate and semi-humid climates. Typically leach out after about 1 year and do not work well in arid climates.
- Lignin sulfides work best in moderate to arid climates, are effective over wide range of temperatures and humidity. Less effective on igneous gravels and those with lower amounts of fines. After heavy rains there is a high potential for leaching and thus a road surface failure.
- Petroleum emulsions provide effective dust control in all environments and aggregate types. Work best with material having low amounts of fines. Waste oil

is an effective dust suppressant, however is not environmentally friendly. A high level of surface stabilization and dust control.

- Enzyme stabilizers provided promising results over wide range of climates and aggregate types. Work particularly well with clay and organic material. Least susceptible to leaching. More expensive. Require most care in application.
- Numerous waste products have been tried showing promising results. Ground bituminous shingles reduced dust emissions significantly for more than a year following treatment.
- Lower vehicle speeds and lower weights will help reduced wearing of aggregate and generation of dust. Variable tire pressure controls resulted in up to 80% reduction in dust.
- Need proper road design and quality construction – crown, slope, drainage, material gradation, and use of high quality aggregates. Also need an effective maintenance program – key to long term dust control. Chemical suppressants should be considered after assuring previous factors have been exhausted in their proper use.
- Dust suppressant used needs to be properly selected based on climate, traffic type, material type and gradation and potential environmental impacts of suppressants use.