Paving Decisions for Laramie County Roads

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December, 2006

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Foreword

Laramie County has 1251 miles of roads, of which 1041 are gravel surfaced. Average Daily Traffic (ADT) on the gravel roads ranges from less than 50 to several hundred vehicles per day. Cost to the County to maintain these gravel roads also varies considerably, from a few hundred to several thousand dollars per mile per year.

As traffic load increases, cost to maintain the roads also increases. At some point, the cost to pave a road would appear to be recovered by savings in maintenance costs. The relationship between ADT and maintenance costs is, however, neither consistent nor straightforward. Therefore, determination of when it is appropriate to pave a gravel road is not a simple matter.

A related problem is determination of whether a proposed new road should be gravel or paved.

This report investigates these problems, using data from Laramie County, the experience of other jurisdictions, and recent research to attempt to provide a rational basis for policy on when to pave existing gravel roads and on when to require that new roads be paved.

This report revises parts of the document “Laramie County, Wyoming Road Maintenance Plans and Procedures”, prepared by BenchMark of Cheyenne, P.C., dated April 1999. The revised material updates some of the information based on recent traffic data, maintenance cost data, and research; and focuses on providing a basis for decisions on paving new and existing roads.

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Executive Summary

The decision on whether to pave a gravel road, or whether to require that a developer provide paved roads in County subdivisions, involves consideration of the costs and benefits to several parties: the general public, users of the roads, developers, and commercial interests affected by the efficiency of the road system.

The general public benefits from reduced cost of road maintenance of a paved road. But the cost of the investment in constructing a paved road, and possible social costs of accidents ("crash costs") that may result from higher speed and traffic volume, complicate the financial analysis.

In addition to the "agency costs", that is, the direct costs to the County government to improve and maintain a road, the type of road surface generates costs and benefits to other parties. A paved road provides benefits to several segments of the population. Users of the road benefit from a better and faster ride and lower operating costs; abutting property owners and the general public benefit from reduced pollution of air and water, and possible enhancements of property values.

This report reviews the current literature on the subject and discusses the costs and benefits of paving existing gravel roads, and the costs and benefits of gravel *versus* paving for new roads and streets in the County, particularly in new residential subdivisions.

There is no single overall convenient measure of when paving a road is economically indicated. The volume of traffic provides a clue, but historical cost records do not indicate that traffic volume alone is a reliable predictor of maintenance cost, and so must be considered along with several other factors.

A step-by-step analysis procedure for making the paving decision is presented, considering the relevant costs and benefits to the various parties. A method to factor in the non-economic issues is suggested. An economic analysis of a hypothetical pavement decision illustrates the method and some of the problems. The need for historical data or at least credible estimates of the costs and benefits is explored. The objective is to provide the decision-making officials with a method to make effective, realistic, and defensible decisions based on sometimes limited available information.

Section 1 - Introduction

Purpose

The purpose of this study is to provide to officials of Laramie County a basis for rational decisions regarding upgrading unpaved roads and for requiring new roads to be designed and constructed as paved sections.

Background

Gravel roads account for a large fraction of the road network in Laramie County. Of a total of 1251 miles, about 1041 miles (83 percent) consists of gravel roads (Wyoming Department of Transportation Data quoted by Sackett, 2004). Gravel roads often are considered to be a serious maintenance, safety, and public relations issue. Local road officials would in most cases much prefer to maintain paved roads, and most (but not all) residents prefer paved roads to serve their property. Gravel roads may be less safe and are certainly more expensive for frequent users. “Many people who live on gravel surfaced roads are simply waiting for the day when those roads will be paved with an asphalt surface. Where there is a high or increasing level of traffic on the gravel road, it is probably only a matter of time before this is done. But for other gravel roads serving sparse populations and carrying low volumes of traffic, these roads will remain gravel surfaced for the foreseeable future.” (Skorseth, 2003)

The subject of paving gravel roads has attracted the attention of a number of investigators. Some of the research provides information directly relevant to the present study. Others, while not directly applicable to the issue at hand, nonetheless provide valuable insights.

The references listed below were those most used in the present study. Several others were consulted and will be referred to as they are used. Appendix A provides the complete list of references used.

> Alzubaidi (1999) describes present practices in the operation and maintenance of gravel roads and presents a comprehensive literature survey of current and recent research. Alzubaidi states that deterioration of a gravel road is due to the action of traffic, rain, wind, and grading and concludes from an extensive review of the literature on the subject that “traffic is the greatest cause of wear of the road”.
>
> Zimmerman and Wolters (2004) attempt to develop practical methodologies and models that local road agencies can use to determine when to maintain, upgrade, or downgrade road surface types on local road segments. The procedures proposed in the present study (Section 5) are based to a great extent on those proposed by Zimmerman and Wolters.

The research described by Jahren *et al.* (2005) examines the costs to construct and maintain various types of road surfaces. It identifies possible threshold values of ADT to consider upgrading a road from gravel to hot mix asphalt paving.

"When to Pave a Gravel Road" (Kentucky Transportation Center, 2000) is an informal and non-technical (and widely-quoted) discussion of factors that local governments should consider when contemplating paving of a gravel road. This short paper provides a checklist of considerations that should be carefully evaluated.

"Laramie County, Wyoming Road Maintenance Plans and Procedures" (Benchmark 1999) is the direct predecessor to the present report, and is the only reference that applies specifically to Laramie County. Benchmark collected maintenance and construction costs where they were available and estimated costs where they were not. Based on a cost benefit analysis, Benchmark concludes that it is economical over a 20 year period for the County to pave and maintain any road where the existing maintenance cost exceeds $20,280 per year. Benchmark also concludes that in cases where the developer is required to initially construct a road, it is economical for the County to require the pavement of any road where the projected maintenance cost exceeds $10,197 per year.

This report will examine the conclusions and recommendations of the previous work, as well as updated cost records for Laramie County, to develop a plan for managing the decision on paving of roads in Laramie County.

Objective

It seems intuitive that at some point the level of traffic and other factors will dictate that a gravel road be considered for paving. Because of the costs of maintaining gravel roads, of upgrading to paved roads, and construction of new paved roads, as well as the variation in user costs and other parameters (dust, erosion, safety), it is essential that the decision on when (or whether) to pave be made on as rational a basis as possible. The cost of making the wrong decision will be substantial. The objective of this report is therefore to increase, to the extent possible, the probability of making the right decision.

Overview

Section Two will discuss the relative costs of roadway maintenance and improvements. A major component of the decision to pave or not pave a road is the relative costs. In order to develop a policy we will need reasonable estimates of the various costs of building, operating, and maintaining the roads. Specifically, we must estimate the costs of upgrading unpaved roads and the costs of maintaining and operating paved and unpaved roads. With this information, we can perform an economic analysis of the alternatives and, in principle, select the most economic alternative.
Section Three will discuss indirect costs and benefits, as well as costs that are direct but difficult to estimate. Changes in the tax base or accident rates are examples of indirect costs. Changing costs of

snow removal, weed control, signs, and other highway services are examples of direct but hard to estimate costs. Also discussed in this section will be non-agency costs, i.e., costs to users, adjacent landowners, and the general public. These costs include vehicle operating costs (fuel, maintenance), dust, and traffic effects. Section Three will also discuss non-economic considerations, i.e., factors for which costs and benefits cannot be attached but are nonetheless factors which decision makers must take into account. Examples are political (wishes of the public), likely effects on future development, effects on mail and school bus routes, and effects on agricultural and commercial truck traffic.

Section Four will include economic analyses using various assumptions of direct and indirect costs and discuss the effects of varying parameters. Effects of the validity of the assumptions and the scatter of data on the results will be explored.

Section Five will develop a model for decision making and a procedure for implementing it. The model will provide decision makers with the ability to account for relevant costs and benefits of a paving decision and suggest ways to handle indirect costs and hard-to-determine costs.

The concluding section, Section Six, will summarize the results of the investigation and present recommendations. The primary recommendation will concern policies for paving existing roads and requiring paving on new roads, depending on the actual or expected ADT.

Section 2 - Roadway Maintenance and Improvement Costs

In order to determine the optimum policy for paving local roads, it is necessary to first develop reasonable estimates of the various costs of building, operating, and maintaining the roads. Specifically, we must estimate the costs of upgrading unpaved roads and the costs of maintaining and operating paved and unpaved roads. With such information, we could perform an economic analysis of the alternatives and, in principle, select the most economic alternative.

Gravel roads have lower construction costs than paved roads. For very low volume roads, maintenance costs are also relatively low. Gravel roads require grading, shaping, and regular addition of gravel. Dust control is often necessary. These costs increase significantly as traffic volume and weights increase. Eventually, it appears that the capital expenditure to improve a gravel road by paving it would be repaid by lower maintenance costs.

Obtaining reliable cost data is, however, elusive. Records of maintenance costs for Laramie County roads show that these costs vary widely. The costs would be expected to depend on a large number of variables. Some of the variables, for example width of road, ADT, terrain, condition of subgrade, length of the segment, and distance from aggregate sources, could be determined for each section of road. However, such surveys would require a good deal of field work, would be expensive and time consuming, and would in the end yield large amounts of data most of which would be of questionable value. Furthermore, such data exhibit such wide variation from road to road as to make it useless for creating deterministic models. That is, it is not possible to estimate with a suitable degree of confidence the future cost of maintenance for a specific road, given the ADT and other parameters. It is, however, possible to estimate average costs of a larger number of roads, using average values for the various parameters, with a somewhat greater degree of confidence. Therefore, road construction, operation, and maintenance costs will be estimated based on average costs. Some actual costs will be higher, some lower than the estimates, but the overall average of actual costs should be not too far off the overall average of estimated costs.

The problem of lack of extensive cost data is not unique to Laramie County; road authorities everywhere have the same problem. Several approaches to the problem have been proposed for other jurisdictions. Some of those that may have application to Laramie County will be discussed here.
The costs of interest to this investigation are maintenance costs of unpaved roads, cost to pave an unpaved road, maintenance costs of paved roads, and various indirect costs. Each of these costs is discussed below.

A final note of caution: The cost data reported below from various sources are not consistent, and it should not be attempted to use these data to estimate the actual costs of construction or maintenance in Laramie County (or anywhere else). Our purpose is to determine the relative costs of maintenance of paved and unpaved roads, to relate these costs to characteristics of the roads (primarily ADT), and to attempt to determine the optimal time to pave a gravel road or to determine whether a new road should be constructed as a paved road.

Maintenance Costs - Paved and Unpaved Roads

Various methods have been used to determine maintenance and improvement costs for local roads for the purpose of comparing the relative costs and benefits of paving them. Several are summarized here. In each case, investigators have attempted to determine the factors that predict maintenance costs. One would intuitively expect a relationship between ADT and maintenance cost -- the more a road is used, the more wear and tear and therefore more maintenance costs would be expected. While all the studies which consider the relationship between ADT and maintenance costs report a positive correlation, the relationship is not as straightforward as one might hope. There are too many other factors, many of which are harder to quantify than ADT. All the approaches allow for consideration of other factors, as well as a considerable application of judgment.

Benchmark of Cheyenne (1999)

<u>Unpaved Roads</u>

Benchmark classifies roads according to the type of maintenance required:

A. Frequent Maintenance with Chloride
B. High Level of Maintenance with Water
C. Above Average Maintenance
D. Typical Maintenance

For each of these classifications, the number of hours required per mile for motor grader and, where required, for water truck were estimated for one maintenance cycle. For the "frequent maintenance with chloride" class, the number of gallons of chloride per maintenance cycle was also estimated. The frequency of maintenance for each class of road and the estimated labor and equipment costs for graders and water truck and the cost per gallon of chloride were used to estimate the annual cost per mile for each class of road.

Benchmark considered only the costs associated with the maintenance of the roadway surface. It is noted that "Other costs such as mowing, signing, etc. should not vary significantly with the type of surface or the amount of grading, and are therefore, not included".

The cost estimates obtained by Benchmark for each of the maintenance categories are summarized as follows: (The details of Benchmark's analysis are shown in Appendix B of this report.)

Roads Requiring Frequent Maintenance with Chloride	$42,640 per mile per year
Roads Requiring a High Level of Maintenance (with water)	$13,520 per mile per year
Roads Requiring Above Average Maintenance	$ 7,280 per mile per year

Roads Requiring Typical Maintenance $ 3,640 per mile per year

Paved Roads

Benchmark calculates the costs for paving and maintaining paved roads based entirely on the initial cost of paving and of periodic overlays over the expected 20 year life of the pavement, all costs reduced to present value using a discount factor based on an annual rate of return of 3 percent. The costs used by Benchmark for paving and maintaining paved roads (1999 dollars) per mile over the 20 year life of the road are:

	Cost	**Present Value of Cost (3% rate)**
Initial paving	$150, 000	$150,000
1" Overlay after 5 years	37,000	31,916
2" Overlay after 10 years	74,000	55,063
1" Overlay after 15 years	37,000	23,750
2" Overlay after 20 years	74,000	40,974
Total	$372,000	$301,703

Note: It is unlikely that the County would maintain paved roads according to this schedule. It seems more likely that chip sealing and crack sealing would be applied at the 5 and 15 year points rather than 1" overlays. The maintenance costs as shown are therefore probably greater than the actual costs would be.

Laramie County Maintenance Cost Records

The most natural place to look for a relationship between maintenance costs and traffic volumes would be actual costs for maintenance of roads for which ADT data is also available. Maintenance costs for 55 unpaved road segments in Laramie County for Fiscal Year 2005 were analyzed. The data are included as Appendix C to this report. Annual maintenance cost per mile varies from about $584 to $20,348.

The Laramie County data for FY05 show a very small correlation (0.29) between ADT and maintenance cost per mile. There are several possible reasons why the relationship is so weak. There may have been recording errors, but such errors would be expected to cancel out. Any systematic recording errors would affect the data, but would be in the same direction and therefore not affect the correlation of the data. The Laramie County data do not include information on width of road or other factors other than ADT which might affect cost, but effects would be also be expected to cancel out. Costs of improving or paving gravel roads may have been incorrectly included in the data base as maintenance, which would considerably skew the results. The small correlation is positive, which is expected, but, whatever the reason for the low value of the correlation, the Laramie County FY 2005 cost data do not provide a basis for inferring maintenance costs of gravel roads based on ADT alone.

We would expect the maintenance cost of a road to be affected by the speed of the vehicles using it. However, for the Laramie County data, there was virtually no correlation between the maintenance cost per mile and the posted speed limit (which is assumed to be related to the actual speeds of vehicles using the road.)

Jahren *et al.* (2005)

The research described by Jahren *et al.* examines the costs to construct and maintain various types of road surfaces. It identifies possible threshold values of ADT to consider upgrading a road from gravel to hot mix asphalt paving. The procedure was to develop a cost analysis based on the history of spending on low-volume roads in various counties in Minnesota, to develop a method for estimating the cost of maintaining gravel roads, and to develop an economic analysis method that can serve as a starting point for analysis to aid in making specific decisions on whether and when to pave.

Jahren *et al.* collected maintenance cost data for gravel and paved roads. The Minnesota Department of Transportation State Aid Office (MNDOT-SAO) had collected data from reports of approximately 50 of the 87 counties in Minnesota for the period 1997 through 2001. Jahren *et al.* used the reports of the 16 counties that had costs broken down for all the maintenance categories. The authors acknowledge that this "sample of convenience" is not a true random sample; however, since this sample provided the most detailed information, it was used for data analysis "...in the hope that this sample of convenience approaches the quality of a true random sample".

Using the sample data from one county (Waseca) the authors formed the hypothesis that the annual maintenance costs per mile for a gravel road increases as the ADT increases, and attempted to verify the hypothesis with data from the other counties.

Since the maintenance data set from the sixteen counties was large, and the study involved interviewing county personnel, the scope of the study required that the authors further reduce the number of counties. Five counties were selected to provide a representation of data from various regions throughout the state of Minnesota. The list was subsequently reduced to four counties when it was found that one of the counties had a unique agreement with townships for maintenance responsibilities and cost sharing, and it was not feasible to make the cost data comparable to that of the other counties.

As in the case of Benchmark, Jahren *et al.*, adjusted the cost results for maintenance of paved and unpaved roads to include only costs that were influenced by surface type: smoothing surface, minor surface repair, reshaping, resurfacing, bituminous treatments, and dust treatments. Activities not included were cleaning culverts, and ditches, brush and weed control, snow and ice removal, traffic services and signs, culverts, bridges, guardrails, washouts, seeding and sodding, and other tasks not affected by surface type.

Table1 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 1997 to 2001. Jahren *et al.* note that there are few miles of paved road in the low-traffic categories and few miles of gravel road in the high-traffic categories. The authors also point out that the category from 150 to 199 ADT is the closest to having 50 percent 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.

Table 1
Surface-Related Maintenance Cost per Mile vs. ADT
for Four Counties in Minnesota from 1997 to 2001

Traffic Volume	Cost per Mile for Gravel	Gravel Mileage	Cost per Mile for Bituminous	Bituminous Mileage	Total Mileage	Percent Bituminous
0-49	1639	252	767	3.6	256	1%
50-99	1851	359	2041	33.8	393	9%
100-149	1788	143	2116	70.6	214	33%
150-199	1878	71	1958	84.2	155	54%
200-249	2466	34	1446	120	154	78%
249-300	2746	1	1623	109	110	99%
300+	1847	10	1199	887	897	99%

Source: Charles T. Jahren, Duane Smith, Jacob Horius, Mary Rukashaza-Mukome, David White and Greg Johnson, "Economics of Upgrading an Aggregate Road", Minnesota Department of Transportation, January, 2005.

The authors proceed to develop a method of estimating maintenance costs. The method is based on costs of equipment, labor, and material, as well as assumptions of road cross sections, gravel thickness, and frequency of maintenance. The estimates for the costs of maintaining a gravel road, grading and resurfacing for a five year regraveling cycle are shown in Table2. (Note that Table 2 shows six years; the sixth year begins a new 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 to obtain $20,800. The resulting average cost per year is $4,160. Note that Jahren *et al.* do not distinguish among the various classes of road. Therefore, these results are not directly comparable to those obtained by Benchmark (1999).

Jahren *et al.* present an "average" cost per mile to resurface a rural unpaved road as $131,600, based on data from several Minnesota counties. Jahren assumes the asphalt surface to be constructed in year 1 for $130,000 per mile and maintained at a cost of $1600 per mile for the first year and for subsequent years. Seven years beyond the initial surfacing, a seal coat is applied at an estimated cost of $6,000 per mile. It is also necessary to continue maintenance expenditures of $1600 per mile 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 or surfacing. Jahren estimates the overall average annual maintenance cost per mile for the asphalt road at $2460, including the annual and seventh-year expenditures.

Table 2
Maintaining/Grading and Re-graveling/Surfacing Costs for Five-Year Cycle

Year	1	2	3	4	5	6	Totals
Grading							
Equipment	$800	$800	$800	$800	$800	$800	$4,800
Labor	$600	$600	$600	$600	$600	$600	$3,600
Resurfacing							
Materials	$7,000					$7,000	$14,000
Equipment	$4,200					$4,200	$8,400
Labor	$2,600					$2,600	$5,200
Annual Totals	$15,200	$1,400	$1,400	$1,400	$1,400	$15,200	$36,000
Cumulative Costs		$1,400	$2,800	$4,200	$5,600	$20,800	

Source: Charles T. Jahren, Duane Smith, Jacob Horius, Mary Rukashaza-Mukome, David White and Greg Johnson, "Economics of Upgrading an Aggregate Road", Minnesota Department of Transportation, January, 2005.

Zimmerman and Wolters (2004)

The objectives of this study, prepared for the South Dakota Department of Transportation, were to:

1. Model agency costs and certain user costs as functions of surface type and other potentially significant variables, such as materials availability, structural condition, traffic, and environmental factors.
2. Develop practical methodologies for using agency and user cost models to determine when to maintain, upgrade, or downgrade road surface types on local road segments.

A step-by-step procedure was developed by which the agency can input data on maintenance costs for four types of road surface (hot mix asphalt, blotter, gravel, and stabilized gravel), various user and non-user costs, subjective estimates of non-economic factors, and interest rates. Using either a manual process or a computer spreadsheet, the user can compare the present value of costs of various options.

A useful feature of the report to the present project is the large amount of cost data collected from local road authorities. The report includes data on maintenance costs for the various road surfaces and characteristics of the road sections. Although specific values of the South Dakota data are not likely to be directly applicable to roads in Laramie County, they are quite useful for comparison of the effects of the various characteristics (terrain, ADT, truck traffic, and subgrade condition) on maintenance costs. The South Dakota data are provided as Appendix D to this report.

Analysis of the data obtained by Zimmerman and Wolters for South Dakota roads shows a correlation of agency costs versus ADT of 0.7. This is a considerably higher correlation than that of the Laramie County records described above, somewhat closer to what might be expected. The South Dakota data also include several factors other than ADT that could affect costs: terrain, subgrade condition, truck traffic, and distance to aggregate source. However, there was, somewhat surprisingly, virtually no correlation between maintenance cost and distance to aggregate source. The average maintenance cost for roads on “poor” subgrades was about 16 percent higher than those on “good” subgrades.

Discussion of the Cost Statistics

It is important to note that the cost data discussed in this section and elsewhere in this report are useful for analysis only. They are not appropriate for estimating costs at the project level, or for application to any specific road. Furthermore, most of the cost data do not contain information on the width of the roads, and the maintenance costs per mile would be expected to vary with the width. So these are average figures with doubtful application to any particular road.

Jahren *et al.* note the following limitations on analyses based on historical cost data:

> “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...”
>
> “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.”

Because of the questionable value of the historical records reported in the Laramie County cost data, Jahren *et al.*, and Zimmerman, it seems preferable to predict maintenance costs with a cost estimate rather than rely on statistics from historical records.

Section 3 - Other Costs and Benefits

Possibly the most noticeable immediate effects of paving gravel roads are the consequences for the maintenance budget. However, there are other costs and benefits associated with the decision on whether to pave, some of them significant. In cases where the relative maintenance costs are inconclusive or uncertain, consideration of the "other costs and benefits" may drive the decision. In fact, in some cases these considerations may override those of direct costs.

Four types of costs and benefits are discussed in this section. Indirect agency costs and benefits are those that will affect the finances of the County in areas other than the maintenance budget. Other factors will clearly affect the maintenance budget but in ways that are difficult to quantify. Non-agency costs and benefits affect citizens or organizations other than the County government. Sometimes the interests of the County and individuals will coincide; sometimes not. Finally, there may be non-economic costs and benefits; i.e., factors about which the County or others may have clear preferences but which do not affect the financial bottom line.

Inclusion of various other costs and benefits to one or another of these categories is for convenience in presentation and in some cases somewhat arbitrary, and some of the categories may overlap.

Indirect Costs and Benefits

If a decision to pave a road decreases (or increases) the maintenance budget, the costs and benefits are direct. There are likely to be other costs or benefits that are real but not direct. For example, paving a gravel road could increase the value of property in the vicinity and therefore an increase in the tax assessment. Jahren *et al.* (2005) note that:

> "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 road facilities."

Reduced erosion (discussed in more detail below) may result in less maintenance of ditches and culverts. The extent of any indirect costs and benefits will be unique to each case, but should be considered and, if possible, quantified and made a part of the decision process.

Difficult-to-Estimate Direct Costs and Benefits

Some costs and benefits are clearly direct, that is, they will either be a benefit or detriment to the budget of the Public Works or other County department or departments. When a gravel road is paved, some maintenance costs are reduced (grading, gravel replacement, dust control) while other costs may increase.

Jahren *et al.* refer to this as a shift to maintaining a higher level of service. They note, "…increased brush and weed control, services, signage, pavement marking, snow and ice removal, and traffic control devices are typically needed for a heightened level of service." For one thing, the public expects a higher level of service on a paved road, particularly in snow and ice control. But the increased speeds require that brush and weeds be kept further from the edge of the road. The increased speeds also require increased sight distances. If costs of such improvements are not included in the original cost of the paving, they will certainly show up later.

Non-Agency Costs and Benefits

Reduced Pollution from Dust and Erosion

Benchmark (1999) noted that it is difficult to assign a specific monetary benefit to the reduction of dust resulting from paving a road. However, dust pollutes the air, and the residents living adjacent to a gravel road can be expected to be supportive of getting the road surfaced. All gravel roads will produce dust, some more than others, depending on traffic, road material, and rainfall. Paving a gravel road eliminates dust from that road. The benefits to the surrounding property are substantial. Dust can cause asthma, allergies, and other health-related problems for some people. The removal of the necessity for constant cleaning of the home would likely be sufficient reason for supporting a paving project for most nearby residents. In agricultural areas, the elimination of the constant cover of dust on crops and vegetation is an added benefit.

Dust also contributes to air and water pollution. An effective dust control program would help mitigate the effects of dust, as well as reduce material loss on high traffic roads. But dust control is expensive, must be applied annually to be effective, and, as Skorseth and Selim (2000) point out, when dust control on high traffic roads begins to be an issue, many agencies will face pressure to pave the road.

Paving also reduces erosion of road materials by wind and water. When vehicles travel unpaved roads, the force of the wheels causes pulverization of surface material. The strong air currents and the turbulent wake behind the vehicle blow about particles lifted and dropped from the wheels. (U.S. Environmental Protection Agency, no date)

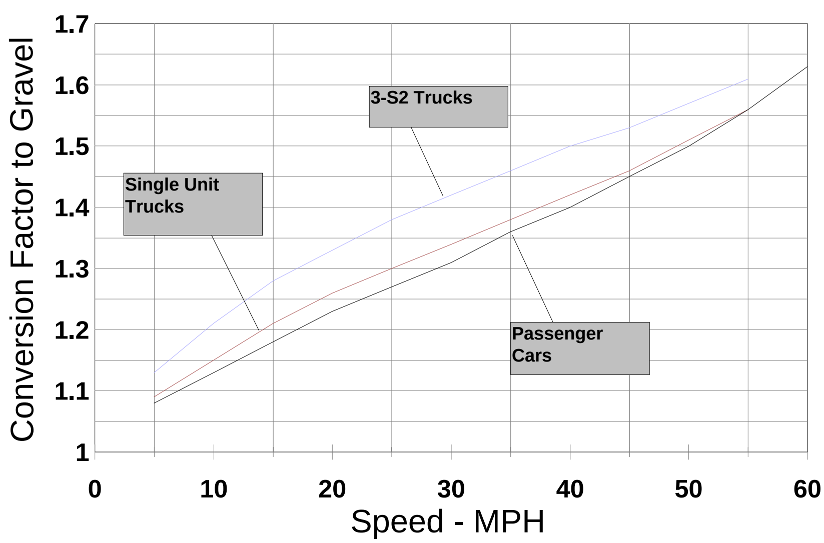
In addition to surface degradation, erosion of unpaved roads degrades the road's drainage system by filling ditches with aggregate that ought to remain on the road. As the drainage system clogs with eroded material, the detritus finds its way into streams, polluting these resources and filling them by sedimentation. The sediment also can introduce toxic contaminants from vehicles and activities associated with road construction and maintenance. (Kuennen, 2005) And, of course, the eroded material must be replaced, adding to the maintenance cost.

Vehicle Operating Costs

It costs more to operate a vehicle on gravel roads than on paved roads. Higher rolling resistance, roughness, and dust associated with unpaved roads leads to higher fuel costs, tire wear, engine wear, oil consumption, and vehicle maintenance costs. In contrast to the difficulty of assigning a specific monetary benefit to the reduction of dust resulting from paving a road, Benchmark (1999) notes that it is possible to quantify the relative cost of operating a vehicle on different types of road surfaces.

Considerable research on user operating costs for various surfaces consistently shows that the results are considerable. A widely referenced chart from AASHTO's "A Manual on User Benefit Analysis of Highway and Bus Transit Improvements", using data employed by Benchmark (1999) and Kentucky Transportation Center (2000), and included here as Figure 1, shows total operating costs for passenger cars traveling at 30 miles per hour on an unpaved road to be higher than those on a paved road by a factor of about 1.3, and increasing to a factor of about 1.5 at 50 miles per hour. The relative effect on operating costs for trucks is higher.

Figure 1
Impact of Gravel Surfaces on User Cost



Source:
Benchmark of Cheyenne (1999)

Zimmerman and Wolters (2004) provide another chart that relates vehicle operating costs per mile as a function of ADT for several road surfaces. For example, the vehicle operating costs per mile on a road with an ADT of 350 is shown as $310,000 for the paved (asphalt) road and $500,000 for a gravel road, a factor of 1.6. This is comparable to the results reported in the AASHTO chart, which would be expected, since both charts use the same source data. We will use the Zimmerman and Wolters chart in Section 5 of this report.

Alzubaidi (1999) refers to research in Sweden that indicates depreciation of vehicles operating mainly on paved roads is 15 percent less than those operating on gravel roads.

It can therefore be seen that differences between user costs on unpaved roads and on paved roads are substantial and may be sufficient to affect the outcome of the paving decision.

Safety

Paving a road improves the skid resistance and stopping distance. Loose gravel, soft spots, and other characteristics of gravel roads that can surprise or distract a driver are eliminated. Unless the improvement is carefully planned, however, the increase in safety can be illusory. Drivers will be tempted to drive faster on a paved road, whether or not sight distance and lane width are adequate, or if bridges are wide enough. Paving before the design deficiencies are corrected will be likely to make the road less safe, not more so. “As speed increases, the road must be straighter, wider, and as free as possible from obstructions for it to be safe. ... Considering these and other safety and design factors in the early stages of decision making can help to achieve the most economical road and one that will meet transportation needs. It makes no sense to pave a gravel road which is poorly designed and hazardous.” (Kentucky Transportation Center, 2000).

Property Values and Future Development

Increase in the tax base was discussed above as a possible “indirect” benefit of paving a road. The increase in property value should also be considered as a non-agency benefit. An increase in the livability of a piece of property, the reduction in nuisance dust and mud, and a safer and more pleasant road would be likely to translate into a higher value of the property. The improved access provided by paved roads can make an area more attractive to development, thereby increasing the value of property served by the improved road.

Mail and School Bus Routes

Mail routes and school bus routes may have to be adjusted as a result of road improvement. This can be either a cost or a benefit, depending on the immediate situation. A related effect could be the need for school bus turnouts because of the higher speed or volume of traffic.

Non-Economic Costs and Benefits

In many cases the expressed wishes of the public may drive the paving decision. Jahren (2005) notes, for example, that people fed up with the dust, mud, and general inconvenience of unpaved roads can assert their wishes to their elected officials in emphatic ways. If successful, such airing of grievances can decide the issue without regard to the economic facts. 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.

Of course, opinions on paving of gravel roads can go both ways. If paving a road is expected to result in increased traffic, particularly truck or agricultural equipment traffic, residents in the area could have a quite rational reason for preferring to keep the road as it is. Gravel roads are inherently appealing to some people in some areas of the United States, although probably not noticeably in Laramie County. The Philipstown (New York) Dirt Road Association, for example, actively lobbies for keeping "dirt" (by which they mean gravel) roads and opposes paving of low volume roads. The Association supports its position based on "maintenance and rehabilitation, scenic preservation, environmental impacts, costs, and safety". The Association addresses costs in a pamphlet "The Road Myths of Philipstown" (Philipstown Dirt Road Association, 2005) in which it is asserted that "The truth is that it costs Philipstown tax payers about twice as much to maintain a paved road."

Maricopa County, Arizona encountered similar resistance to paved roads from some citizens (Sowers 1998). In a newspaper feature article several years ago (Sowers 1998), one resident is quoted as objecting: "Dirt roads are one of the few remaining symbols of Scottsdale's rapidly vanishing Western flavor. Dirt roads are part of living in the country."

Section 4 - Economic Analysis

An economic analysis will help in the decision on the whether to upgrade a gravel road to asphalt, or whether to require that a new road be paved. In this section a procedure is presented in which the relevant costs and benefits are explicitly considered and which provides a basis for the decision. The process is illustrated by two examples. Assumed costs and benefits are used for illustration.

Example 1. Paving Decision for an Existing County Road

Assume a gravel road with maintenance costs of $7000 per mile per year, as determined either from estimates or from cost records in which the County has confidence. It is estimated that an investment of $150,000 per mile will be required to pave the road. Over the 20 year life of the road, maintenance costs will be as shown in Table 3.

Table 3
Example of County Road Cost Data

Year	Initial Investment	Crack Seal	Seal Coat	Striping & Marking	Patching & Misc.	Total	Discount Rate	Present Value
0	$150,000				$500	$150,500	0.03	$150,500
1					$500	$500	0.03	$485
2					$500	$500	0.03	$471
3					$500	$500	0.03	$458
4			$7,000	$300	$500	$7,800	0.03	$6,930
5		$1,600			$500	$2,100	0.03	$1,811
6					$500	$500	0.03	$419
7					$500	$500	0.03	$407
8			$7,000	$300	$500	$7,800	0.03	$6,157
9					$500	$500	0.03	$383
10		$1,600			$500	$2,100	0.03	$1,563
11					$500	$500	0.03	$361
12			$7,000	$300	$500	$7,800	0.03	$5,471
13					$500	$500	0.03	$340
14					$500	$500	0.03	$331
15		$1,600			$500	$2,100	0.03	$1,348
16			$7,000	$300	$500	$7,800	0.03	$4,861
17					$500	$500	0.03	$303
18					$500	$500	0.03	$294
19					$500	$500	0.03	$285
20		$1,600	$7,000	$300	$500	$9,400	0.03	$5,205
					Total Present Value			$188,382

The present value of the (direct agency) costs of the paving option is $188,382 per mile, assuming crack sealing at 5-year intervals, seal coat and striping and marking at 4-year intervals, at costs as shown, and a discount rate of three percent.

For estimated annual maintenance costs of $7000 per mile per year for the gravel road, the present value of the maintenance cost, again assuming the 3 percent discount rate, is $104,142. In this case, based on direct agency costs alone, it is not economically feasible to pave the road.

If it is assumed that the road requires a high level of maintenance with water, the annual maintenance cost for the gravel road is considerably higher. If the annual maintenance cost per mile doubles to $14,000, the present value of cost over 20 years also doubles, to $208,285 and paving is the clear economic choice.

Of course, the cost estimates should be valid ones. For example, if only one mile of a gravel road is treated with calcium chloride and nine miles are only "average" maintenance, use of the costs of chloride treatment for estimating the maintenance cost of the entire ten miles will give a distorted (and not very credible) result.

Example 2. Paving Decision for a New Local Road

In the previous example, it is implicitly assumed that the same party (in this case the public) bears the costs and reaps the benefits of the decision. There are no non-agency costs, and the non-agency benefits are not considered. In the case of a new road that is to be paid for by a developer, the decision on paving is complicated by the fact that paving involves non-agency as well as agency costs and benefits. Benchmark (1999) points out that a developer would pass on the cost of paving to the buyers of the lots, with the result that the people who use the street and benefit from the paving would pay for it.

Using the same fictitious road as in Example 1, we now assume that it is a Rural Local road; i.e., paved travel way with shoulders and ditches (no curb, gutter, or sidewalk).

The benefits of constructing a paved road instead of a gravel road are as follows:

Reduction of maintenance cost:

Present value of maintenance cost of chloride treatment:	$ 208,285
Present value of maintenance of pavement	($ 37,882)
Net benefit to the public of paving	$ 170,403

Vehicle operating cost (Zimmermann and Wolter, 2004)

20 year vehicle operating cost per mile, gravel (ADT 350)	$ 500,000
20 year vehicle operating cost per mile, paved	$ 310,000
Net saving in operating cost over 20 years	$ 190,000
Present value of net saving, discount rate 3% (assumed compounded annually and spread equally over the 20 years)	$ 141,336

Without considering any other benefits, such as safety, reduction in dust, and property values, the investment in paving of $150,000 in this example returns a benefit of $170,000 to the County in maintenance cost saving and $141,336 to users in vehicle cost saving.

These examples illustrate the process for economic analysis; they do not make a case for or against paving specific existing roads or requiring paving for new roads. It should be noted that changes in the parameters (paving cost, maintenance cost, ADT, estimated user costs as a function of ADT) will affect the outcome and could result in the opposite decision. Also, inclusion of other user costs and benefits in the mix may move the result one way or another.

The examples also do not suggest how the costs or benefits should be shared between the general public (the County), local users, and developers. In Section 5 we will develop a procedure for calculating the costs and benefits of paving. The question of how costs and benefits are shared is a political issue and is not thoroughly addressed in this report.

Section 5 - Development of a Procedure

This section presents a procedure for comparing the costs and benefits of paving an existing gravel road. Zimmerman and Wolters (2004) developed a model for comparing costs among four types of surface (hot mix asphalt, blotter, gravel, and stabilized gravel). In this report only asphalt and gravel are considered. The inclusion of other road surface types in the analysis would be straightforward provided there were reliable construction and maintenance cost data or credible cost estimates available for these surface types.

Zimmerman and Wolters also provide a software tool in addition to a manual procedure. Although only a manual procedure is developed in the present report, the method would lend itself quite readily to a spreadsheet application.

In the interest of simplification, Zimmerman and Wolters use a fixed discount rate (3.5%) and do not provide for variation of the discount rate in the model. However, since the rate can materially affect a decision on paving, the model presented here includes consideration of the time value of money.[1]

The analysis model presented here is based on an assumed 20 year life of the road. Other periods can be used for analysis by substituting the appropriate values in the worksheets.

Procedure and Example Analysis

This section outlines a formal method of analysis to indicate the most appropriate decision on whether to pave an existing road or whether a proposed road should be gravel or asphalt surface.

The procedure described in this section is adapted from the methodology presented in Zimmerman and Wolters.

The input data for the analysis should ideally be based on Laramie County cost records or engineering estimates for a specific project. Where such data or estimates are not available, the values used in the following example may be used as default values. The default values may be used as provided or modified according to the judgment of the analyst. However, to the extent the default data are used, results will be based on average or approximate data. The model also uses default maintenance schedules as a basis for estimates of maintenance costs. Actual maintenance procedures and the corresponding costs can and should be substituted where they are available. Blank worksheets are provided in Appendix F.

<u>Step 1. Identify the Road Section</u>

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[1] For a review of use and application of the formulas and interest tables, see any standard text on engineering economy, for example, Thuesen and Fabrycky (1964); or financial management, for example Schall and Haley (1977). Winfrey (1969) provides a more extended and detailed discussion with specific reference to highways.

Worksheet 1 is the Summary Sheet for the analysis. Enter the identifying data of the roadway under consideration:

Line 1, Road Name: Enter the Road Name *(Gunbarrel Road in our hypothetical example)*

Line 2, Location: Enter the limits of the road section. *(The example is for the fictitious Gunbarrel Road between Shallowford Road and Lightfoot Mill Road.)*

Line 3a, Length: Enter the length of the road section in miles. *(2.3 miles in the example)*

Line 3b, ADT: Enter the average daily traffic (ADT) associated with the section of roadway. The ADT may be based on traffic counts, if available, or, if necessary, estimated. Based on the observed or estimated ADT, the average ADT over the 20 year period should be projected. *(350 in the example)*

Worksheet 1. Summary of Cost Analysis

Line 1. Road Name:	Gunbarrel Road	
Line 2. Location:	between Shallowford Road and Lightfoot Mill Road	
Line 3a. Length	2.3 miles	
Line 3b. ADT:	350	
Cost Information (Present Values)	**Hot Mix Asphalt**	**Gravel**
Line 4. Agency Total Costs per Mile	$234,848	$245,164
Line 5. User Average Total Costs - Vehicle Operating Costs per Mile	$310,000	$500,000
Line 6. User Average Total Costs - Crash Costs per Mile	$181,670	$38,920
Line 7. Total User Costs per Mile (Line 5 + Line 6)	$491,670	$538,920
Line 8. Weighting Factor for user costs	0.15	0.15
Line 9. Weighted User Costs per Mile (Line 7 * Line 8)	$73,751	$80,838
Line 10. Total Costs per Mile (Line 4 + Line 9)	$308,599	$326,002

Step 2. Determine the Agency Costs

The next step is to calculate the agency component of the total costs expected over the life of the roadway. Worksheets 2 and 3 outline the calculations for hot mix asphalt and gravel, respectively.

Worksheet 2. Agency Costs for Hot Mix Asphalt Roadway Section

Column 1	Column 2	Column 3	Column 4	Column 5
Treatment	Number of Applications Per Year (times/yr)	How Often the Treatment is Applied (years between applications)	Costs Per Application (cost/mile)	Costs per Mile per Year column 2 * column 4 column 3
Line 1: Crack Sealing	1	5	1600	$320
Line 2: Seal Coat	1	4	7000	$1750
Line 3: Overlay	1	20	74000	$3700
Line 4: Striping and Marking	1	4	300	$75
Line 5: Patching	1	4	500	$125
Line 6: Other				
Line 7: Total Maintenance Costs Per Mile Per Year (Sum Lines 1 through 6)				$5970
Line 8: Analysis Period (years) (usually 20)				20
Line 9: Discount Rate (as determined by the County)				0.035
Line10: Equal-payment-series compound amount factor for the analysis period and discount rate (from formula or table, Appendix E)				14.2124
Line 11: Present Value of Maintenance Costs per Mile (Line 7 * Line 10)				$84,848
Line 12: Initial Construction/Major Rehabilitation Costs per Mile				$150,000
Line 13: Present Value of Total Costs per Mile (Line 11 + Line 12)				$234,848

Copy line 13 to Worksheet 1, line 4.

Worksheet 3. Agency Costs for Gravel Surface Roadway Section

Column 1	Column 2	Column 3	Column 4	Column 5
Treatment	Number of Applications Per Year (times/yr)	How Often the Treatment is Applied (years between applications)	Costs Per Application (cost/mile)	Costs per Mile per Year column 2 * column 4 column 3
Line 1: Blading	50	1	95	$4,750
Line 2: Regravel	1	5	10500	$2,100
Line 3: Reshape Cross Section	1	5	7000	$1,400
Line 4: Spot Graveling	2	1	4500	$9,000
Line 5: Other.				
Line 6: Total Maintenance Costs Per Mile Per Year (Sum Lines 1 through 5)				$17,250
Line 7: Analysis Period (years) (usually 20)				20
Line 8: Discount Rate (expressed as a decimal, e.g. 4% = 0.04)				.035
Line 9: Equal-payment-series compound amount factor for the analysis period and discount rate (from formula or table, Appendix E)				14.2124
Line 10: Present Value of Maintenance Costs per Mile (Line 6 * Line 9)				$245,164
Line 11: Initial Construction/Major Rehabilitation Costs per Mile				
Line 12: Present Value of Total Costs per Mile (Line 10 + Line 11)				$245,164

Copy line 12 to Worksheet 1, line 4.

Step 3. Determine the User Costs

After determining agency costs, the next step is to calculate the user cost portion. This step includes Vehicle Operating Costs and Crash Costs. The user cost portion of the analysis may be used in full, used partially, or totally excluded from the analysis. The utilization of user costs in life cycle cost analysis is supported by many agencies, including the Federal Highway Administration and it is recommended that users of this report also consider user costs. (Zimmerman and Wolters, 2004)

Step 3a. Determine the Vehicle Operating Costs

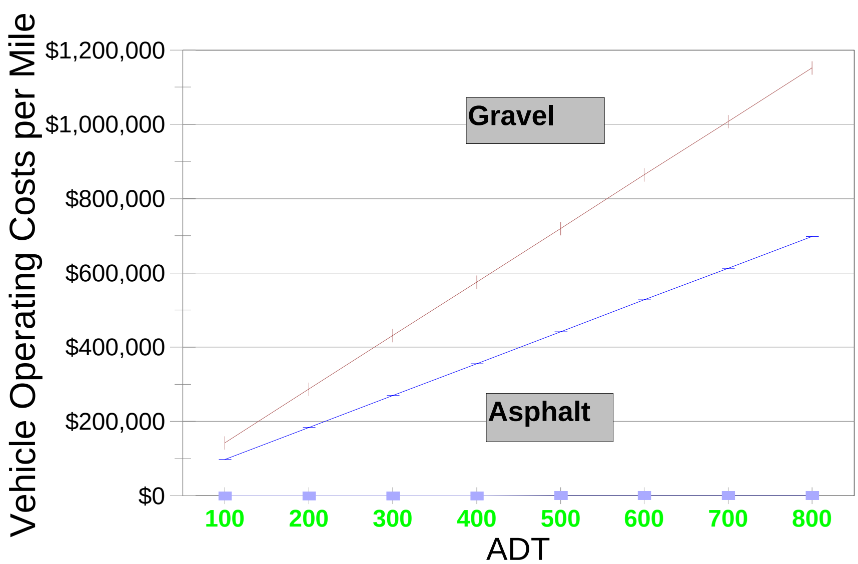
Figure 2 shows the variation of vehicle operating costs per mile as a function of ADT for Hot Mix Asphalt and Gravel roads. Zimmerman and Wolters (2004) compiled the data from their survey of South Dakota counties using methods developed by Winfrey (1969). Vehicle operating costs include cost of fuel, tires, engine oil, maintenance, and depreciation. Using Figure 2, enter the plot at your

known ADT level and determine the corresponding vehicle operating costs for asphalt and gravel surfaces. Enter these values on Line 5 of Worksheet 1.

Example: Using Figure 2, consider our example road with ADT of 350. Draw a line upward through the two surface type cost lines. The vehicle operating costs for the asphalt and gravel are $310,000 and $500,000, respectively. These numbers would be added to Line 5 of Worksheet 1.

Figure 2

Vehicle Operating Costs vs. ADT



(Source

: Adapted from Zimmerman and Wolters, 2004)

Note that the costs shown in Figure 2 are cumulative costs over a 20 year period. If a different time period were used, the costs would be adjusted proportionally. Also note that the time value of money is not considered. However, if the precision of reducing all costs to present value were desired, the cumulative 20 year costs could be divided by 20 and the result considered an annual cost, which could be reduced to present value. Considering the uncertainty of the operating costs, this degree of refinement is probably not warranted.

Step 3b. Determine the Crash Costs

The analyst may wish to consider the effects of paving on the cost of highway crashes. The crash costs for a given roadway are based upon the frequency of fatal, injury, and personal damage crashes that occur within a given time frame on a roadway section.[2] Based upon your knowledge of the road section, use Table 4 to determine the crash potential you expect per mile of roadway over a 10-year period. While crash potential is provided for a 10-year period, the crash costs were determined for a 20-year analysis period. The crash potential rates were provided for a 10-year period rather than a 20-year period because it is easier to estimate crash potential over a shorter time period. ... Once the crash potential level is determined for the given pavement section, Table 5 can be used to determine the average accident costs for each surface type. These results can be added to line 6 of Worksheet 1.

Table 4
Crash Potential (based on 1-mile roadway section)

Crash Potential	Expected Number of Crashes by Type over 10 Year Time Period
None	No fatalities, injuries or personal damage only crashes
Low	No fatalities, one or no injury crashes, and fewer than four personal damage only crashes
Medium	*Option 1:* No fatalities, one to three injury crashes, and four to six personal damage only crashes
	Option 2: One fatality, one or two injury crashes, and four or fewer personal damage only crashes
High	*Option 1:* No fatalities, more than three injury crashes, and more than six personal damage only crashes
	Option 2: One fatality, more than two injury crashes, and more than four personal damage only crashes
	Option 3: More than one fatality

Source: Zimmerman and Wolters (2004)

[2] The remainder of this paragraph is taken *verbatim* from Zimmerman and Wolters (2004).

Table 5
Average 20-year crash costs per mile of pavement per surface type per crash potential level for rural roads

Surface Type	None	Low	Medium	High
Asphalt	$0	$ 20,110	$ 181,670	$ 398,900
Gravel	$0	$ 3,800	$ 38,920	$ 222,300

Source: Zimmerman and Wolters (2004)

Example: Over a 10-year time period, the county expects to have five fatalities, ten injury and ten personal damage crashes over a 5-mile roadway section. The expected crash rates correspond to one fatality, two injury, and two personal damage crashes per mile of pavement over the next 10 years (each crash figure is divided by five to convert the accidents to a per-mile basis). Using Table 4, the County determines that the crash rates for the roadway section correspond to a "medium" crash potential.

Using Table 5, the County determines their "medium" crash potential relates to crash costs of $181,670 and $38,920 for the asphalt and gravel roads, respectively. The costs from Table 5 would be added to line 6 of Worksheet 1.

<u>Step 3c. Scale the User Cost</u>[3]

Before adding user costs to the agency costs, it may be appropriate to adjust the user costs. Some agencies discover that during a cost analysis such as this, the very large costs associated with vehicle operating and crash costs often overwhelm the agency (construction and maintenance) costs of a specific project. Therefore, the agency may decide to exclude user costs or reduce the associated costs in order to provide costs that are more in line with expected values. This can be done by scaling the user costs calculated in the previous step with a weighting factor that is representative of the importance of user costs within the agency. A weighting factor of 1.0, for example, is representative of using the user costs as they are calculated (in other words, no scaling of user costs is conducted). A weighting factor of 0 eliminates user costs from consideration in the analysis. Therefore, a reasonable weighting factor should be selected between the values of 0 and 1.0. When selecting the weighting factor, the agency should consider the relative magnitude of the user costs to the agency costs and select a weighting factor that represents the importance of one value to the other. The final weighting factor that is selected should be added to line 8 of Worksheet 1. If you are not comfortable determining your own weighting factor, Table 6 provides a recommended range of weighting factors depending upon the level of importance your agency places on the user costs.

[3] This section is taken *verbatim* from Zimmerman and Wolters (2004)

Table 6
Recommended Weighting Factors for User Costs

Level of Importance Assigned to User Costs	Proposed Weighting Factor Range
Low	0 - 0.05
Medium	0.05 - 0.10
High	0.10 - 0.15

Source: Zimmerman and Wolters (2004)

For the example, we assume the County places a high level of importance on user costs and use a weighting factor of 0.15. This factor goes to line 8 of Worksheet 1.

Step 4. Summarize Total Costs

The total relative costs of the alternative surface treatments are determined by filling out the remainder of worksheet 1. Determine the total user costs (line 7) for each surface type by adding the vehicle operating costs (line 5) to the crash costs (line 6). Multiply the total user cost by the weighting factor for user costs (line 8) to obtain the weighted user cost (line 9). Finally, add the agency total cost (line 4) to the weighted user cost (line 9) to obtain the total cost per mile for each surface type (line 10). The surface with the lowest costs is the most cost-effective choice based solely on economic factors.

In the example, the total cost per mile are $238,848 for paving the road; $245,164 for maintaining the gravel road. Therefore, with the assumptions used for costs, paving the road is the least cost option by a small margin. Note that relatively small changes to the input parameters could reverse the result, so it is important that the input parameters be carefully chosen, by reliable historic cost data if available; otherwise by scrupulously prepared estimates.

Note that non-agency costs, other than vehicle operating costs and crash costs, are not included in this procedure. If the agency wishes to include such factors as property values, pollution, dust, and erosion, another line could be added to worksheet 1 to account for these costs. If, as is more likely, specific costs of these items cannot reasonably be obtained, these items can be treated as non-economic factors in step 5 below.

Step 5. Evaluate Non-Economic Factors[4]

In some cases, an agency may select a local road surface based solely on the economic factors calculated earlier. However, in most cases, there are other issues besides total costs that come into play when deciding on a roadway surface. These issues include political factors, growth rates,

[4] This section is extensively adapted from Zimmerman and Wolters (2004)

housing concentration and dust control needs, mail routes, and industry/truck traffic. Worksheet 4 allows the agency to take both economic and non-economic factors into consideration. The following directions provide a step-by-step procedure for completing Worksheet 4.

1. Add or delete "factor categories" in the first column of Worksheet 4 as appropriate to the road under consideration. Assign rating factors to the factor categories. In order to assign rating factors, you must comparatively weigh the importance of each of the six factor categories and assign higher ratings to those factors that are most important to your agency. The total of all rating factors must add up to 100 percent. You may use any combination of rating factors that make sense to your agency, as long as the sum equals 100. For instance, an agency that places greatest importance on total costs and minor importance to the other factors might assign a rating factor of 50 to Total Costs and 10 to each of the other 5 categories. After the rating factors are selected, they should be added to the Rating Factors column in Worksheet 4. When applying these rating factors, remember that the same rating factors will be used for each surface type.

Worksheet 4. Scoring Table for Economic and Non-Economic Factors

Factor Categories	Rating Factor (%)	Asphalt		Gravel	
		Scoring Factor	Total Score (Rating Factor* Scoring Factor)	Scoring Factor	Total Score (Rating Factor* Scoring Factor)
Total Costs	.80	2	1.6	1	0.8
Political Issues	.10	1	0.1	2	0.2
Growth Rates					
Housing Concentration/ Dust/Erosion Control	.10	2	0.2	1	0.1
Mail Routes					
Industry/ Truck Traffic					
Total Score	100%		1.9		1.1

2. The next step is to assign scoring factors. For each of the categories, comparatively rank the surface types by assigning scoring factors in Worksheet 4 for each of the surface types. A rating of 2 should be assigned to the surface that does best in the given category while a rating of 1 should be assigned to the surface that does worst in that category. If the two surface types perform equally in a given category, equal scoring factors can be assigned to each.

3. With rating and scoring factors assigned, the next sep of the evaluation is to calculate the scores for each of the surface types. For each factor category within each surface type, multiply the scoring factor by the rating factor to determine the total score. For this calculation, the rating factor, which previously was given as a percentage, should now be expressed as a decimal (e.g. 5%=0.05) when multiplying by the scoring factor. Adding the total score for each factor category together and recording them in the bottom row of Worksheet 4 will then determine the total scores for each of the surface types.

For the example, we suppose the County fills out Worksheet 4 as shown.

The use of the scoring table to include non-economic factors in this case expands the difference between the choices. Use of these factors can be subject to abuse by parties wishing to tilt the selection one way or the other, so its use should be carefully controlled and transparent. When used properly, however, it should give decision makers a clearer picture of what is the best choice for county roads.

4. The last step in the evaluation is to determine the most appropriate surface type for the roadway section. Once the total scores for each surface type have been determined, the surface type with the highest score should be the selected surface for the given roadway section.

Note that the worksheets are easily expandable to consideration of additional surface types. Zimmerman and Wolters (2004), from which much of the discussion in this section is adapted, considers four surface types and should be consulted for a thorough discussion, with examples, of the method. The document is available online; see Appendix A, References, for the web site.

This section is a lightly abridged version of Appendix G, “Technical Brief”, of Zimmerman and Wolters. The major differences are that we consider only two surface types in the model, while Zimmerman and Wolters consider four; and we consider variations in the time value of money in the analysis of agency costs, while Zimmerman and Wolters do not.

Section 6 - Summary and Recommendations

Summary

This report has considered the related problems of when to pave a gravel road and when to require a new road to be paved. Recent research on the subject has based the analysis on either comparisons of historical cost statistics for building and maintaining roads with various surfaces (Zimmerman and Wolters, 2004) or with estimates of costs (Jahren et. al, 2005). Based on the scatter of cost data for Laramie County, a model using estimated costs was developed. When reliable statistical records of construction and maintenance costs for gravel and paved roads become available, the model can be adapted to be used with the historical records. Even if good correlations between ADT and maintenance costs could have been established, the resulting cost comparisons would still depend on site-specific conditions. Therefore, the analysis will always depend to some degree on estimates based on these conditions.

In addition to the direct costs to the County for construction and maintenance, we have discussed various other cost and benefit considerations, especially user costs of the various surfaces. Consideration of these "non-agency" costs can have a decisive effect on the paving decision.

The model provides for consideration of accident costs and non-economic considerations if the County wishes to do so. The model can be expanded to other types of surface provided cost data are available or can be estimated. The non-economic factors are based largely on the judgment and priorities of the County, and their validity in the analysis depends on the objective consideration of non-economic factors by the decision makers.

Recommendations

1. Cost records of Laramie County and conclusions reached by other investigators indicate that roads with ADT greater than 200 or 250 are candidates for consideration for improvement by paving. It is not likely that paving of roads with this amount of traffic will be justified based solely on comparison of construction and maintenance costs to the County. However, consideration of user costs and non-economic factors may tilt the balance in favor of paving for such roads. If there is demand from the public for paving of such roads, an analysis such as that outlined in Section 5 of this report should be considered.

   Recommendation: Consider a road with ADT of 200 or higher a possible candidate for paving, particularly if there is substantial public demand for it.

2. For roads with ADT above 350, the maintenance cost of gravel roads can be expected to increase substantially as traffic increases. User costs and non-economic factors will also increase the likelihood that analysis will indicate that the road should be paved. Of the 55 unpaved county road sections listed in Appendix D, twelve have ADT greater than 350. These roads (and other county roads not listed but in a similar ADT range) should be analyzed. Also, roads with a high maintenance cost per mile should be analyzed.

Recommendation: Perform an analysis as outlined in Section 5 on gravel roads with ADT of 350 or greater. The priorities should be based on maintenance costs, dust and erosion, or other issues that make a road a "problem road", not solely on ADT.

(It should be noted that high ADT alone does not necessarily indicate that paving is indicated. For example, County Road 128A in Schmidt Subdivision is among the most heavily used unpaved roads in the County, with ADT of 1708 vehicles per day; however, maintenance costs, according to County records, are relatively low. This road is in an industrial subdivision, and appears to be densely compacted with little dust problem. On the other hand, Wayne Road from Riding Club to Moriah, with an ADT of 289, has the highest maintenance cost of the 55 roads listed. There may be a good reason, or it may be statistical aberration, but it is an anomaly that should be investigated.)

3. In the case of new roads that will be built at the expense of the developer, the analysis is similar to that for existing County roads. The important difference, of course, is that the benefits accrue primarily to the County in lower maintenance costs and to the residents in the benefits that accompany paved roads (dust and erosion avoidance, safety) while the costs accrue to the developer. Benchmark (1999) suggests that it is economical for the County to require paving of any road where the projected maintenance exceeds $10,197 per year, or roughly an ADT of 350. We believe this threshold is about right, and the current standard of a buildout ADT of 500 is too high. Previous experience of the County indicates that residents will demand, and are willing to pay for paved roads at significantly lower traffic volumes. (The evidence for this is anecdotal, but we believe it to be accurate.) At densities that generate ADT of 350 or more, the developer should be able to recoup the additional cost in the added value of the lots. The cost will accrue to the developer, or, more accurately, to the residents of the new development who are the parties who receive the non-agency benefits, including increased property value. Decisions should not benefit, for example, residents of the development at the expense of the public at large.

   Recommendation: In county residential subdivisions, require a paved section local county road where buildout ADT exceeds 350. If analysis shows a paved section is indicated for a lower ADT, the paved section should be required regardless of ADT.

4. The analysis described in Section 5 includes several inputs that are subjective in nature, or at least depend on judgment; for example, the weights given to non-economic factors. To avoid the appearance of adjusting these factors to achieve a desired result, it is essential that the analysis be completely objective in appearance as well as in fact. Parties adversely affected by a decision can be expected to review the analysis closely and be on the lookout for any holes in the logic.

   Recommendation: Parties with an interest in the outcome of an analysis should have the opportunity to review the analysis and have all the input assumptions explained, and have the right to appeal a decision to an impartial body (e.g., the Board of County Commissioners or a body appointed by the commissioners for the purpose).

Appendix A -References

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Appendix B - Estimated Maintenance Costs per Mile

(Reproduced from Benchmark, 1999)

Estimated Maintenance Costs per Mile

This comparison considers only the costs associated with the maintenance of the roadway surface. Other costs such as mowing, signing, etc. should not vary significantly with the type of surface or the amount of grading, and are therefore, not included.

General Assumptions:

Hourly Cost of a Motor Grader with Operator	$70.00
Hourly Cost of a Water Truck with Operator	$60.00
Cost of Chloride per gallon	.30

Roads Requiring Frequent Maintenance With Chloride

Each mile requires:

Motor Grader 8 hrs. @ $70.00	=	$560.00
Water Truck 8 hrs. @ $60.00	=	480.00
Chloride 2000 gal. @ 0.30	=	600.00
Cost / Treatment		**$1,640.00**

Required biweekly – $1,640 x 26 = Cost/Mi/Yr. = $42,640.00

Roads Requiring a High Level of Maintenance (with water)

Each mile requires:

Motor Grader 4 hrs. @ $70.00	=	$280.00
Water Truck 4 hrs. @ $60.00	=	240.00
Cost / Treatment		**$520.00**

Required biweekly – $520.00 x 26 = Cost/Mi/Yr = $13,520.00

Roads Requiring Above Average Maintenance

Each mile requires:

Motor Grader 2 hrs. @ $70.00	=	$140.00

Required weekly – $140.00 x 52 = Cost/Mi/Yr = $7,280.00

Roads Requiring Typical Maintenance

Each mile requires:

Motor Grader 2 hrs. @ $70.00 = $140.00

Required biweekly – $140.00 x 26 = Cost/Mi/Yr. = $3,640.00

In summary, the estimated costs per mile for four levels of maintenance in Laramie County are:

Chloride maintenance	$42,540
High Maintenance	13,520
Marginal maintenance	7,280
Typical maintenance	3,640

Appendix C - Maintenance Cost Data for Various Roads in Laramie County

Adapted from Data Furnished by Laramie County Public Works

Road Maintenance Costs July 1, 2004 thru June 30, 2005

Sort on: ADT

Road	From/To	Length (miles)	Maintenance Cost	Cost/Mile	ADT	Post MPH	Map Ref.	Functional Classification
Woods Rd	Columbia to Mynear	0.25	$635.15	$2,540.60	47	30	D-52	L
Beckle Rd	Christensen to Whitney	1.00	$2,788.37	$2,788.37	93	35	D-53	L
Space Dr	Four Mile to Tranquility	0.74	$3,981.93	$5,380.99	94	30	D-49	L
E. Powell Rd	Yellowstone to Chisolm	0.50	$2,028.56	$4,057.12	97	20	D-34	L
Jack Rabbit Rd	Four Mile to Riding Club	1.00	$2,055.58	$2,055.58	116	30	D-36	L
Christensen Rd	Pershing to Tate	0.21	$684.32	$3,258.67	119	30	D-81	L
Eagle Dr	Powderhouse to Converse	0.80	$3,230.59	$4,038.24	122	30	D-49	L
Road 146	201 to 208	7.00	$12,768.00	$1,824.00	130	30	B	
Winddancer Rd	Iron Mtn. to Moriah	0.75	$1,488.17	$1,984.23	138	35	D-20	L
Columbia Dr	Powderhouse to Converse	0.60	$2,574.42	$4,290.70	143	30	D-49	L
Road 207	138 to State 217	2.00	$5,184.00	$2,592.00	146	45	B	
Deerbrooke Trail	Four Mile Loop	1.01	$2,604.63	$2,578.84	149	30	D-34	L
Roundtop Rd	Horsecreek to Arabian	0.25	$288.57	$1,154.28	161	40	D-16	C
Yarina Way	Christensen to Shapra	0.40	$913.23	$2,283.07	162	30	D-40	L
Ketcham Rd	Roundtop to Rolling Hills	0.50	$2,201.97	$4,403.94	164	30	D-73	C
Aztec Dr	Christensen to Shapra	0.40	$1,015.84	$2,539.60	165	30	D-40	L
Glencoe Dr	Ridge to College	0.25	$738.06	$2,952.24	170	30	D-51	L
Skyline Dr	Woods to Van Buren	0.26	$845.08	$3,250.31	182	30	D-52	L
Mt. Meeker Rd	Bishop to Green Mtn	0.20	$798.79	$3,993.95	184	25	D-33	L
Mynear St	Woods to Van Buren	0.26	$667.11	$2,565.81	185	30	D-52	L
E. Laughlin Rd	Yellowstone to Bomar	0.30	$1,200.14	$4,000.47	193	30	D-34	L
Rucker Rd	Rolling Hills to Roundtop	0.25	$586.18	$2,344.72	196	30	D-86	L
Mynear St	Ridge to College	0.25	$1,134.59	$4,538.36	201	30	D-51	L
Treadway Trail	McKinney Loop	0.86	$7,264.19	$8,446.73	203	30	D-86	L
New Bedford	East of College	0.50	$1,484.75	$2,969.50	208	30	D-51	L
Delaware St	Riding Club to Iowa	0.51	$2,036.68	$3,993.49	210	25	D-20	L
Red Fox Rd	Four Mile to Champion	0.25	$994.91	$3,979.64	212	30	D-36	L
Christensen Rd	Yarina to Child	0.75	$1,683.02	$2,244.03	217	30	D-39	PA
Avenue C-4	Gordon to Fox Farm	0.38	$2,858.67	$7,522.82	221	20	D-106	L

Continued from previous page								
Thomas Rd	Ridge to College	0.25	$2,403.57	$9,614.28	232	30	D-65	L
Woods Rd	Skyline to Mynear	0.25	$1,062.80	$4,251.20	233	30	D-52	L
E. Nation Rd	85 to E. dead end	0.42	$6,872.55	$16,363.21	244	30	D-133	L
Charles St	College to Service Road	0.50	$1,789.01	$3,578.02	246	25	D-79	L
Summit Dr	College to Highland	0.50	$1,754.40	$3,508.80	253	30	D-51	C
Michigan St	Riding Club to Crestview	0.37	$1,578.43	$4,266.03	259	35	D-20	L
Gordon Rd	Ave D to Ave C-4	0.50	$1,889.65	$3,779.30	275	20	D-106	L
Braehill Rd	Columbia to Four Mile	0.25	$3,941.04	$15,764.16	280	30	D-51	L
Wayne Rd	Riding Club to Moriah	0.25	$5,087.06	$20,348.24	289	35	D-21	L
Rock Springs St	Van Buren to Cleveland	0.45	$246.73	$548.29	291	25	D-79	L
Powderhouse Rd	North of Iron Mountain Rd	1.00	$1,245.04	$1,245.04	313	30	D- 7	MA
Tate Rd	Pershing to Christensen	0.96	$4,044.22	$4,212.73	324	30	D-81	L
Telephone Rd	Horsecreek to Foxhill	0.25	$145.27	$581.08	328	35	D-2	C
Horizon Loop	Dell Range to Christensen	0.82	$1,704.43	$2,078.57	345	30	D-67	L
Four Mile Rd	Surrey to Westedt	0.50	$1,459.97	$2,919.94	373	30	D-41	L
Four Mile Rd	Reese to Westedt	1.00	$5,219.19	$5,219.19	416	40	D-55	L
Whitney Rd	Hwy 30 to S dead end	0.70	$1,513.51	$2,162.16	461	30	D-81	C
Braehill Rd	Four Mile to N. dead end	1.00	$7,338.21	$7,338.21	470	30	D-37	L
Road 135	Service Road to 212	1.00	$1,776.00	$1,776.00	505	35	H-5	L
Columbia Dr	at North College	0.48	$4,733.47	$9,861.40	630	30	D-51	L
Avenue D	Fox Farm to Gordon	0.38	$7,611.99	$20,031.55	811	30	D-106	L
Concha Loop	Powderhouse to Hackamore	0.70	$3,661.29	$5,230.41	822	25	D-35	L
Four Mile Rd	College to Braehill	0.47	$6,050.16	$12,872.68	903	30	D-51	L
Whitney Rd	Dell Range to Beckle	1.00	$2,042.34	$2,042.34	1266	35	D-67	C
Road 128A	S. Industrial Dr to S. dead	0.50	$1,425.75	$2,851.50	1708	20	D-108	C
Summit Dr	Ridge to College	0.25	$3,352.15	$13,408.60	1825	30	D-51	MA

Correlation of ADT with Maintenance Cost per mile: 0.29

Appendix D - Cost Data from Various South Dakota Counties

The following pages contain maintenance cost data for hot mix asphalt (HMA) and gravel roads from various counties in South Dakota as presented by Zimmerman and Wolter (2004). These data are presented for readers wishing to compare costs of Laramie County (Appendix C) with those of other jurisdictions.

Agency and user costs for HMA sections per mile for 20-year analysis
Various South Dakota Counties

Road	Surface	Agency Cost	Total User Cost	VOC Cost	Crash Cost	ADT	Length (miles)	Subgrade	Truck Traffic	Dist. to Aggregate Source (miles)	Speed Limit Limit (mph)	Housing Density
Bon Homme Co: CO RD 13	HMA	$57,500	$155,311	$112,707	$42,604	110	6	Good	Low	60	55	Low
Codington Co: 23-6	HMA	$78,335	$832,800	$377,667	$455,133	300	5.3	Good	Low	11	55	Low
Codington Co: 3-5	HMA	$83,016	$270,523	$235,659	$34,864	230	6	Good	Low	7	55	Low
Codington Co: 4-7	HMA	$46,062	$104,389	$63,703	$40,686	70	2	Good	Low	10	55	Low
Davison Co: 30-4-44	HMA	$59,625	$547,688	$345,816	$201,872	380	14	Poor	High	19	55	Low
Day Co: #1	HMA	$66,084	$676,726	$512,303	$164,423	500	26	Good	Low	5	55	Low
Douglas Co: 3-4	HMA	$63,482	$59,061	$56,878	$2,183	63	2	Good	High	10	55	Low
Douglas Co: 3-5	HMA	$53,341	$124,676	$124,676		137	1.75	Poor	Low	10	55	Low
Douglas Co: 500-2	HMA	$65,763	$322,256	$322,256		325	1	Poor	High	6	20	High
Douglas Co: 520-3	HMA	$43,767	$166,982	$166,982		200	1	Good	High	15	30	Low
Douglas Co: 560	HMA	$83,650	$1,117,239	$705,282	$411,957	775	6	Good	High	40	55	Low
Douglas Co: 7-3	HMA	$60,185	$289,938	$286,663	$3,275	315	4	Poor	High	20	55	Low
Lincoln Co: #134	HMA	$83,963	$683,623	$682,531	$1,092	750	4				55	
Lincoln Co: #148	HMA	$71,343	$457,932	$455,021	$2,911	500	6				55	
McCook Co: 16A	HMA	$35,194	$232,999	$184,429	$48,570	180	1	Poor	High	14	55	Low
McCook Co: 25	HMA	$72,121	$190,458	$174,183	$16,275	170	5	Good	Low	2	55	Low
McCook Co: 25A	HMA	$45,857	$103,270	$81,968	$21,302	80	3	Good	High	11	55	Low
McCook Co: 4A	HMA	$55,776	$198,827	$184,429	$14,398	180	11	Good	Low	10	55	Low
McCook Co: 9A	HMA	$63,581	$543,437	$502,057	$41,380	490	4	Good	Low	16	55	High
Miner Co: #7	HMA	$96,680	$676,500	$391,318	$285,182	430	11	Good	High	20	55	Low
Miner Co: Road #17	HMA	$74,788	$206,813	$200,209	$6,604	220	11	Good	Low	35	55	Low
Minehaha Co: #105N	HMA	$94,946	$738,495	$637,029	$101,466	700	8				55	
Minehaha Co: #119	HMA	$119,489	$1,588,852	$1,365,061	$223,791	1500	6				55	
Minehaha Co: #137	HMA	$125,594	$2,320,710	$2,275,102	$45,608	2500	17				55	
Pennington Co: Sheridan Lake Rd	HMA	$131,440	$713,916	$703,031	$10,885	700	5.47	Good	Low		50	High
Perkins Co: C2	HMA	$53,247	$70,966	$66,599	$4,367	65	1	Good	Low	1	55	Low
Perkins Co: C2b	HMA	$77,068	$70,966	$66,599	$4,367	65	1	Good	High	2	55	Low
Potter Co: #155	HMA	$49,463	$93,777	$81,968	$11,809	80	16	Good	High	20	55	Low
Sanborn Co: #9-0	HMA	$79,393	$291,216	$263,912	$27,304	290	14	Good	Low	4	55	Low
Turner Co: #17	HMA	$89,180	$1,377,554	$1,350,430	$27,124	1318	3	Good	High	7	55	High
Turner Co: #41	HMA	$50,984	$715,460	$295,763	$419,697	325	6	Good	Low	18	55	Low
Walworth Co: Township Indian Crk.	HMA	$41,135	$204,921	$204,921		200	1	Good	Low	6	55	Low

Notes:

1. ADT and user costs for Perkins Co. C2 and C2b are identical; therefore suspicious

2. ADT for Douglas Co. 3-4 shown as 62.5; rounded here to 63

Correlation ADT/Agency Cost 0.70

Agency and User Costs for Gravel Sections per Mile for 20-year Analysis Various South Dakota Counties

Road	Agency Cost	Total User Cost	ADT	Length (miles)	Terrain	Subgrade	Truck Traffic	Distance to Aggregate Source (miles)	Speed Limit (mph)
Bon Homme Co: Avon Twp	$22,698	$96,126	62	0.8	Flat	Poor	Low	10	55
Codington Co: 18	$20,572	$85,938	62	6	Flat	Poor	High	10	55
Codington Co: 20-1	$23,879	$256,721	188	4	Flat	Poor	High	11	55
Custer Co: E. French Creek Rd.	$43,961	$109,585	80	16.9	Flat	Good	Low	10	55
Custer Co: Ghost Canyon CS360	$67,939	$829,525	500	7.61	Mountainous	Good	High	15	45
Custer Co: Limestone Rd CS284	$100,508	$605,423	350	8.44	Mountainous	Poor	High	5	45
Custer Co: Lower French Cr CS341	$49,890	$496,471	325	5.93	Mountainous	Good	Low	5	25
Custer Co: Medicine Mtn CS297	$61,854	$326,399	170	4.75	Mountainous	Good	High	5	35
Custer Co: Pass Creek CS273	$41,447	$282,132	205	11.74	Rolling	Good	Low	1	45
Custer Co: PleasantValley FAS715	$46,227	$285,458	200	28.72	Rolling	Good	Low	10	45
Custer Co: Spring Cr Cutoff FAS 152	$26,991	$56,142	46	7.4	Flat	Good	Low	3	45
Custer Co: Upper French Creek CS286	$39,812	$377,233	188	2.96	Mountainous	Poor	Low	4	35
Edmunds Co: #15 South	$23,442	$203,298	145	14.5	Flat	Good	High	46	55
Edmunds Co: #16	$32,888	$87,393	62	8	Flat	Good	High	43	55
Edmunds Co: #26	$45,338	$82,893	60	16	Flat	Poor	Low	52	55
Edmunds Co: #3	$19,194	$47,365	30	14	Rolling	Good	High	8	55
Edmunds Co: #4A	$16,803	$85,210	62	4	Flat	Poor	Low	12	55
Edmunds Co: #5	$19,180	$38,704	25	16	Rolling	Good	High	15	55
Edmunds Co: #6	$16,566	$55,551	35	5	Rolling	Poor	Low	15	55
Edmunds Co: #8	$21,208	$291,479	188	17	Rolling	Poor	High	20	55
Gregory Co: CR-42	$71,406	$190,007	135	10	Flat	Good	High	15	55
Hand Co: County Rd 15-G	$32,904	$109,899	62	5	Flat	Good	Low		55
McCook Co: 23A	$19,879	$97,534	62	3	Rolling	Good	High	18	55
Miner Co: #25	$29,230	$324,247	62	10	Flat	Good	High	3	55
Miner Co: #9	$26,956	$119,526	62	11	Flat	Good	Low	10	55
Pennington Co: East Slate Rd	$44,639	$342,785	70	4	Mountainous	Good	High	10	50
Pennington Co: Edelweiss Mt Rd	$96,010	$528,708	318	3.5	Mountainous	Good		20	25
Pennington Co: Horse Creek Rd	$45,916	$86,917	60	0.32	Mountainous	Good	Low	22	25
Pennington Co: Mystic Rd	$46,714	$320,326	169	7.5	Mountainous	Poor	Low	18	50
Perkins Co: C1	$21,065	$138,352	90	4	Rolling		High	1	55
Perkins Co: C10	$22,441	$33,671	10	6	Rolling		High	9	55
Perkins Co: C13	$14,213	$32,928	20	8	Rolling		High	9	55
Perkins Co: C17	$25,354	$38,431	25	3	Rolling		High	16	55

Perkins Co: C2	$16,767	$78,172	50	4.3	Rolling		High	1	55
Perkins Co: C6	$18,742	$76,862	50	2	Rolling		High	1	55
Perkins Co: T24	$14,138	$18,447	12	5	Rolling		High	14	55
Perkins Co: All FSA	$24,036	$107,113	62	10	Rolling	Good	High	17	55
Sanborn Co: #21	$48,719	$64,626	45	12	Flat	Good	Low	6	55
Turner Co: 34	$19,838	$47,717	35	4	Flat	Good	Low	18	55
Walworth Co: #119	$38,091	$85,210	62	1.5	Flat	Good	Low	7	55
Walworth Co: Township Schlouer Rd	$56,034	$100,445	62	1	Rolling	Good	Low	1	55

Correlation of ADT with Maintenance Cost per mile: 0..6986

Appendix E - Equal Payment Series Compound Amount Factors

Number of Periods	Discount Rate i (percent)						
	2.0	2.5	3.0	3.5	4.0	4.5	5.0
1	0.9804	0.9756	0.9709	0.9662	0.9615	0.9569	0.9524
2	1.9416	1.9274	1.9135	1.8997	1.8861	1.8727	1.8594
3	2.8839	2.8560	2.8286	2.8016	2.7751	2.7490	2.7232
4	3.8077	3.7620	3.7171	3.6731	3.6299	3.5875	3.5460
5	4.7135	4.6458	4.5797	4.5151	4.4518	4.3900	4.3295
6	5.6014	5.5081	5.4172	5.3286	5.2421	5.1579	5.0757
7	6.4720	6.3494	6.2303	6.1145	6.0021	5.8927	5.7864
8	7.3255	7.1701	7.0197	6.8740	6.7327	6.5959	6.4632
9	8.1622	7.9709	7.7861	7.6077	7.4353	7.2688	7.1078
10	8.9826	8.7521	8.5302	8.3166	8.1109	7.9127	7.7217
11	9.7868	9.5142	9.2526	9.0016	8.7605	8.5289	8.3064
12	10.5753	10.2578	9.9540	9.6633	9.3851	9.1186	8.8633
13	11.3484	10.9832	10.6350	10.3027	9.9856	9.6829	9.3936
14	12.1062	11.6909	11.2961	10.9205	10.5631	10.2228	9.8986
15	12.8493	12.3814	11.9379	11.5174	11.1184	10.7395	10.3797
16	13.5777	13.0550	12.5611	12.0941	11.6523	11.2340	10.8378
17	14.2919	13.7122	13.1661	12.6513	12.1657	11.7072	11.2741
18	14.9920	14.3534	13.7535	13.1897	12.6593	12.1600	11.6896
19	15.6785	14.9789	14.3238	13.7098	13.1339	12.5933	12.0853
20	16.3514	15.5892	14.8775	14.2124	13.5903	13.0079	12.4622
21	17.0112	16.1845	15.4150	14.6980	14.0292	13.4047	12.8212
22	17.6580	16.7654	15.9369	15.1671	14.4511	13.7844	13.1630
23	18.2922	17.3321	16.4436	15.6204	14.8568	14.1478	13.4886
24	18.9139	17.8850	16.9355	16.0584	15.2470	14.4955	13.7986
25	19.5235	18.4244	17.4131	16.4815	15.6221	14.8282	14.0939

Note: For any number of periods and interest rate, the corresponding equal payment series compound amount factor is given by:

$$\frac{1 - (1 + i)^{-n}}{i}$$

Where n is the number of periods and i is the interest rate per period, expressed as a decimal (not a percent). For example, for an interest rate of 3.5 percent, use i = 0.035 in the formula.

Appendix F - Worksheet Forms

The following pages in this Appendix contain blank worksheets for use in the analysis described in Section 5 of this report.

Worksheet 1. Summary of Cost Analysis

Line 1. Road Name:			
Line 2. Location:			
Line 3a. Length			
Line 3b. ADT:			
Cost Information (Present Values)		**Hot Mix Asphalt**	**Gravel**
Line 4. Agency Total Costs per Mile			
Line 5. User Average Total Costs - Vehicle Operating Costs per Mile			
Line 6. User Average Total Costs - Crash Costs per Mile			
Line 7. Total User Costs per Mile (Line 5 + Line 6)			
Line 8. Weighting Factor for user costs			
Line 9. Weighted User Costs per Mile (Line 7 * Line 8)			
Line 10. Total Costs per Mile (Line 4 + Line 9)			

Worksheet 2. Agency Costs for Hot Mix Asphalt Roadway Section

Column 1	Column 2	Column 3	Column 4	Column 5
Treatment	**Number of Applications Per Year (times/yr)**	**How Often the Treatment is Applied (years between applications)**	**Costs Per Application (cost/mile)**	**Costs per Mile per Year** **column 2 * column 4 / column 3**
Line 1: Crack Sealing				
Line 2: Seal Coat				
Line 3: Overlay				
Line 4: Striping and Marking				
Line 5: Patching				
Line 6: Other				
Line 7: Total Maintenance Costs Per Mile Per Year (Sum Lines 1 through 6)				
Line 8: Analysis Period (years) (usually 20)				
Line 9: Discount Rate (as determined by the County)				
Line10: Equal-payment-series compound amount factor for the analysis period and discount rate (from formula or table, Appendix E)				
Line 11: Present Value of Maintenance Costs per Mile (Line 7 * Line 10)				
Line 12: Initial Construction/Major Rehabilitation Costs per Mile				
Line 13: Present Value of Total Costs per Mile (Line 11 + Line 12)				

Worksheet 3. Agency Costs for Gravel Surface Roadway Section

Column 1	Column 2	Column 3	Column 4	Column 5
Treatment	**Number of Applications Per Year (times/yr)**	**How Often the Treatment is Applied (years between applications)**	**Costs Per Application (cost/mile)**	**Costs per Mile per Year** **column 2 * column 4** **column 3**
Line 1: Blading				
Line 2: Regravel				
Line 3: Reshape Cross Section				
Line 4: Spot Graveling				
Line 5: Other.				
Line 6: Total Maintenance Costs Per Mile Per Year (Sum Lines 1 through 5)				
Line 7: Analysis Period (years) (usually 20)				
Line 8: Discount Rate (expressed as a decimal, e.g. 4% = 0.04)				
Line 9: Equal-payment-series compound amount factor for the analysis period and discount rate (from formula or table, Appendix E)				
Line 10: Present Value of Maintenance Costs per Mile (Line 6 * Line 9)				
Line 11: Initial Construction/Major Rehabilitation Costs per Mile				
Line 12: Present Value of Total Costs per Mile (Line 11 + Line 12)				

Worksheet 4. Scoring Table for Economic and Non-Economic Factors

Factor Categories	Rating Factor (%)	Asphalt		Gravel	
		Scoring Factor	Total Score (Rating Factor* Scoring Factor)	Scoring Factor	Total Score (Rating Factor* Scoring Factor)
Total Costs					
Political Issues					
Growth Rates					
Housing Concentration/ Dust/Erosion Control					
Mail Routes					
Industry/ Truck Traffic					
Total Score	100%				