ASSET MANAGEMENT FOR WYOMING COUNTIES

Volume I of III

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Disclaimer

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1. INTRODUCTION

In the fall of 2003, the Wyoming Department of Transportation (WYDOT) and the Wyoming T^2/LTAP Center (T^2/LTAP) began planning an asset management program to assist counties impacted by oil and gas drilling with management of their road systems. In the spring of 2004, with approval from their county commissioners, Sheridan, Johnson, and Carbon Counties contracted with T^2/LTAP to implement asset management programs. WYDOT paid for 90% of the program with federal programming funds with the counties funding the remaining 10%.

The overall objectives were to develop an inventory of the counties roads, bridges, culverts, signs, cattleguards, and approaches; to evaluate and assess the condition of these assets; and to estimate the counties' financial needs.

1.1 Oil and Gas Drilling Impacts

"Low–volume rural roads in oil–producing areas were not initially constructed to endure the impact of intense oil field truck traffic. Thus, a condition of persistent rehabilitation was not anticipated under normal operating situations, and complete pavement restoration costs were not normally accounted for in the planning of maintenance. Since typical traffic characteristics and usual vehicle distributions are not applicable to roadways that carry oil field traffic, there is a need to determine the definitive elements of oil field traffic demand." (Mason and Scullion 1983)

Mason and Scullion's report was part of a research project sponsored by the Texas State Department of Highways and Public Transportation during the last boom. They estimated that drilling a single well takes about 60 days, and that 1,365 trucks larger than standard pickups travel to the well site during preparation and drilling; they further estimated that during production, lasting about three years, 150 large trucks per month serve each well. Their study addressed the issues of oil field traffic on paved state highways where the additional drilling traffic had a substantial impact. The situation for the lower volume roads in Sheridan, Johnson, and Carbon Counties is certainly more acute. The counties' roads were not designed to carry the traffic volumes of the Texas state roads, so they are even less able to absorb the influx of drilling traffic.

1.2 Study Objectives

This study was initiated to provide assistance to counties that were experiencing considerable impacts to their road systems from oil and gas drilling but were not receiving sufficient revenue to keep up with these impacts. As drilling expanded from Campbell County into Sheridan and Johnson counties and from Sweetwater County into Carbon County, Sheridan, Johnson, and Carbon counties' road systems were being damaged by the influx of heavy and light truck traffic from drilling activities. Though it was common knowledge that these impacts were significant, the impacts were undocumented. The primary objective of this study was to develop an asset management system for counties in Wyoming. The counties included in this pilot study were Johnson, Sheridan, and Carbon counties. Such a system can be used to identify overall needs. In addition, it will quantify the drilling impacts on infrastructures in these counties. The system developed can then be implemented by other interested counties in the state.

1.3 Report Organization

The findings of this study are summarized in four main elements: this main report; an example annual summary report in Volume II; the appendices to this report in Volume III; and a CD available upon request by contacting either georgeh@uwyo.edu or khaled@uwyo.edu .

This report begins with this introduction, Section 1, which describes how the project was initiated. Section 2 provides background information on asset management, the performance of gravel roads, and dust control agents. Section 3 describes the operational and analytical procedures used in this study. Section 4 contains the results of the data collection and analytical procedures. Section 5 summarizes these results with estimates of the county road networks' financial needs. Section 6 describes the current status of asset management by Wyoming county road and bridge departments. Section 7 contains recommended implementation procedures for other Wyoming county road and bridge departments.

Volume II contains an example that shows how annual reports from the developed asset management system might appear. Such reports summarize the condition of and budgetary needs for a county's transportation assets.

The appendices in Volume III contain additional details of many aspects of this study. They contain photographs of assets in various conditions excerpted from the training materials, published papers generated by this project, descriptions of the analytical procedures used in this study, detailed results obtained from the analytical procedures, and details of the recommendations for implementation in other counties.

The CD contains Volumes II and III of this report, the GIS and rating data for ongoing use by the three counties, a number of maps generated during this study, and the data collection training materials.

2. BACKGROUND

2.1 Asset Management

2.1.1 Network and Project Level Asset Management

The asset management program implemented as part of this project has several basic aspects in both functional and operational terms. Operationally, the program consists of training and data collection, data storage, and analysis. Functionally, there are two primary levels, project level and network level, with several subservient functions within each of the two primary levels. These functions include, on a network level, establishing appropriate allocation of resources between maintenance and construction, between hauling more expensive gravel and surface blading costs, and between repairing and replacing culverts, to name just a few. On a project level, the asset management system is used to recommend specific treatments for a given road section, such as regraveling, asphalt overlays, cleaning culverts, and sign replacement.

2.1.2 Map–Based Asset Management: GIS

Transportation systems are fundamentally spatial. Therefore, incorporating mapping capabilities is highly desirable for a transportation asset management system. Recent advances in geographic information system (GIS) software make such mapping capabilities accessible to even relatively small organizations. Collecting data associated with locations determined by the global positioning system (GPS), then loading this data into a GIS system makes mapping the collected data a fairly straightforward task. On an overall scale, being able to see various features of a transportation network on a map provides a good overall picture of the situation. Perhaps even more important, having maps of a county's system allows road and bridge employees to plan their daily activities more efficiently. This is particularly significant in sparsely populated counties where employees may have to travel upwards of a hundred miles to get from the shop to where work needs to be done. A good GIS–based asset management system lets supervisors know exactly what is out there: What size is the damaged culvert? Is that shotgun–blasted sign a left or right curve? What kind of cattleguard grate needs to be replaced? Without an asset management system, county employees might have to answer these questions by spending several hours and many gallons of gas getting out there and looking at the problem. Asset management systems can pay for themselves simply in hours and miles saved. But the total benefits are far greater. As one documents the overall condition of a county's road and bridge network, funding requests can be based on documented needs, rather than on unsubstantiated opinions.

2.1.3 Asset Management Software

Several software alternatives were considered during the early phases of this study. Asset management systems developed at two other local technical assistance program (LTAP) centers, Michigan LTAP and Utah LTAP, were examined, along with the option of developing a system in house. Ultimately, the Wyoming T^2/LTAP Center decided to develop a system in house, using the ESRI ArcGIS software. (The University of Wyoming is licensed to use these products, so no additional software purchase costs were incurred by the Center when using these products.)

Both the Michigan and Utah LTAP centers' asset management systems did not have well developed systems for gravel roads, a major drawback considering that about 90% of the roads in Sheridan, Johnson, and Carbon counties are gravel. Other problems with these systems also contributed to the decision to develop software in house. The system developed by the Utah

LTAP Center was managed by graduate students, while the Michigan LTAP Center had a staff of several professionals operating their system. Continuity and quality of support were considered significant drawbacks to the Utah system, along with the aforementioned rudimentary gravel roads system. The Michigan system, though very well supported, was not compatible with other systems already in place in a number of Wyoming counties. The inability to transfer data from the Michigan system to the software already in place at many counties made this option undesirable. These flaws with the available existing systems led the Wyoming T^2/LTAP Center to develop software forms, tables, and procedures in–house using the ESRI software.

2.1.4 Training and Data Collection

The training and data collection phase is probably the most difficult aspect of any asset management system. To be of any great value, an asset management system must be kept up to date. Individuals trained to enter data into the asset management system should work closely with those on the ground. Ideally, those with the most immediate access to changes in the road and bridge network would also perform the data collection; sign crews should update sign databases; law enforcement officials should update crash databases; and road maintainers should update road surface databases. Systems should be in place to get the ever–changing data from the field into the asset management system, or the system will quickly lose its value as the information becomes out of date.

2.1.5 Data Storage

Data storage is a relatively simple task once good geographic information system software tailored to the needs of the specific user, such as a county road and bridge department, has been created. Building the software forms, routines, and tables needed to collect and store data has considerable up–front costs, but once the system is up and running, it needs little attention. Of course, there are always modifications – no one thinks of everything at the beginning. For this reason, as well as for any possible troubleshooting and training, a GIS professional should be available for any organization using a GIS–based asset management system.

2.1.6 Data Analysis

Once a GIS–based system for collecting and storing data is in place, analysis is relatively easy. Extracting data and generating maps can be learned by anyone with reasonable proficiency with other software systems, such as spreadsheets and databases. Once the more difficult task of setting up the data collection and storage software has been accomplished, the GIS expert should be able to train other personnel to extract the desired information with relative ease.

2.2 Gravel Roads Performance

While the effects of truck traffic on asphalt and concrete pavements have been well documented, their effects on gravel roads are less well understood. Typical gravel road design methods are largely geared toward new construction, particularly for logging haul roads; design methods and costs for maintenance of gravel roads are not well documented, nor are the impacts of truck traffic on gravel roads' performance. As part of this project, studies have been carried out that monitored the performance of several gravel road sections in an attempt to quantify the effects of truck traffic and other factors on gravel roads (see Appendix A.3).

2.3 Dust Control

Dust control, actions that prevent dust from blowing off the road when vehicles loosen it, has four main benefits: first, the environmental hazards of blowing dust are reduced; second, the loss of binder that leads to washboards, raveling, and potholes is reduced; third, binding the surfacing gravel together increases the road's structural strength, thereby reducing rutting; and finally, the hazards of limited visibility are reduced. The following sections describe some widely used dust suppressants.

Waste oils should not be used as dust suppressants since they are harmful to the environment and they violate United States Environmental Protection Agency (USEPA) rules (Skorseth and Selim 2000).

2.3.1 Chloride Salts as Dust Suppressants

The most common dust suppressants are the chlorides, particularly calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$) (Skorseth and Selim 2000). These products are hygroscopic salts – they bond with water molecules, thereby keeping moisture in the gravel and preventing dust from forming. Typically, these treatments last from one to five years, depending on application rates and other conditions.

The relatively low cost and short lives of these treatments makes them a good option for drilling roads that need to be upgraded for a relatively short time. On the down side, they may lose their effectiveness in very dry conditions – while they hold moisture better than untreated gravel, they will eventually dry out in hot, dry, windy conditions. Chlorides are considerably less effective when the average relative humidity is less than 35%. Also, they may become slick in wet conditions since they hold moisture. To prevent these problems associated with wet and dry conditions, chlorides should be used when the fines content (material passing a #200, 75µm sieve) is between 10% and 20%. With less fines, the binding effect brought about by the salts is not achieved; with more fines, the surface may get very slippery when wet, particularly if the chloride application rate is high.

There are other problems associated with chloride salts, such as corrosion of vehicles and leaching after heavy rains. They may cause environmental harm if they leach into waterways (Lunsford and Mahoney 2001). However, ease of application and relatively low cost make the chlorides an attractive option, especially for roads that are likely to see a lot of use in the short term, making more expensive, long–term structural options less appealing.

There are two ways of applying chlorides, either as dry flakes or as a brine solution. Typical dry flakes with 77% pure calcium chloride, according to USFS specifications, are applied at a rate of from 1.5 to 1.9 psy (0.82 to 1.03 kg/m^2). USFS specifications for brine application rates are 0.29 to 0.36 gsy for 36% calcium chloride brine and 0.40 to 0.50 gsy for 28% magnesium chloride brine. In the 1940's brine rates as high as 1.4 gsy were used *(Lunsford and Mahoney, 2001).* Application rates should be discussed with the distributor. In addition, a product should be tried on a limited scope until it is proven for use with a specific gravel. For a discussion of chloride salts application techniques, see (Skorseth and Selim 2000), pages 53 – 55.

2.3.2 Lignin Sulfonate as a Dust Suppressant

Other options are the resin–based dust suppressants, most commonly lignin sulfonate, sometimes referred to as “tree sap” or lignin sulfide, a combination of sulfuric acid and wood sugars, which is a by–product of the pulp milling industry. The resins act as a binder that provides cohesion for the surfacing gravel. Like the chlorides, the sulfonates also present an environmental risk as they leach out of the gravel. They work by undergoing a chemical cementing reaction, so they cannot reseal themselves after trucks damage the road surface. (Skorseth and Selim, 2000 & Lunsford and Mahoney 2001).

2.3.3 Asphalt as a Dust Suppressant

Historically, asphalts, particularly cutbacks, have been used as dust suppressants. Emulsions have also been used to control dust. Asphalts must be applied with specialized equipment (Skorseth and Selim 2000).

2.3.4 Natural Clays as Dust Suppressants

Natural clays are also an option for dust control. While it may seem counter–intuitive to add clay to control dust, the cohesive nature of clays may serve to bind up the surface, making it tighter and less prone to dust as it holds the silt particles in place. However, like the chlorides, when clays dry out they become less effective and some dust will come up as vehicles drive over the road (Skorseth and Selim 2000).

2.3.5 Proprietary and Other Dust Suppressants

There are many other commercially available dust suppressants. As with the more generic products above, proprietary dust suppressants’ performance varies with different climates and gravel types. It is recommended that a test strip of any dust suppressant be tried before treating a long stretch of road (Skorseth and Selim 2000).

3. METHODS

A comprehensive evaluation was conducted at the beginning of this study to identify the data needed to establish a functional asset management system. As shown in Figure 1, the T^2/LTAP Center developed training materials and data collection techniques. These techniques were used to collect the needed data in the summers of 2004, 2005, and 2006. The collected data were then used to identify the infrastructural needs in the counties included in this study.

The following sections describe the operational and analytical procedures used to carry out the functional objectives of this project. Three separate analytical techniques are used to assess the needs and condition of each county's road system. Figure 3.1 provides an overall schematic representation of the process used to analyze both paved and unpaved roads.

Section 3.6 describes the procedures used to establish each road segment's functional classification. Section 3.7 describes the procedures used to recommend improvements. Section 3.8 describes the estimation of the annual construction and routine maintenance costs. Section 3.9 describes the long–term condition prediction modeling process.

When reviewing this report and assessing each county’s road and bridge departments, it should be kept in mind that they are responsible for more than just roads. This analysis is an incomplete assessment of the departments' needs since it addresses roads, but not bridges.

3.1 GPS and GIS

Field data collection was performed with GPS location of all features. Laptop computers connected to mapping grade GPS receivers stored the location of the features along with their characteristics as entered by the data collectors. Forms were developed by T^2/LTAP that made for easier, more uniform data entry. This data was stored in a GIS, which is simply a database with mapping and location components. T^2/LTAP selected the ESRI ArcGIS software products to acquire, store, and analyze the information gathered.

Students and retirees were hired by T^2/LTAP to perform the data collection. Lacking in experience in the roads business, these people had to be trained in both the software and the road evaluation aspects of this project. The training materials are included on the accompanying CD. Two–person rating teams were sent out with hard copies of maps developed by WYDOT for each county’s road system. With these maps in hand, they drove the road system, creating GIS layers and evaluating the roads.

The data collectors were trained to create and locate the road segments and other features in the GIS using the GPS receivers and the forms developed by T^2/LTAP. Road segments were created in about one–mile increments. The software was set up to associate the geographic information with the data entered in the forms.

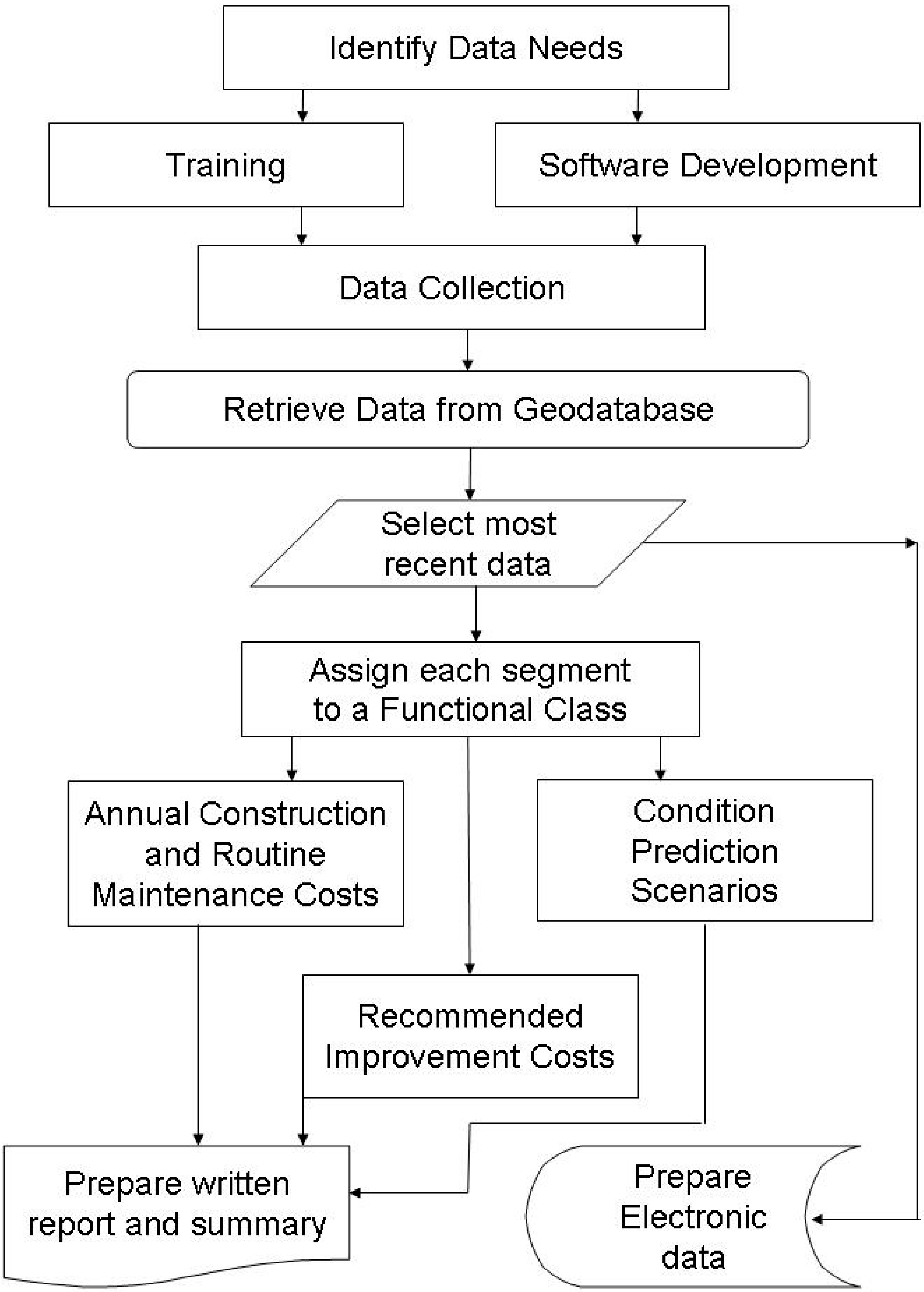

Figure 3.1 Overall roads analytical processes.

3.2 Subjective Ratings and Training

Features – signs, culverts, cattleguards, approaches, and bridges – were measured and rated using methods developed by T^2/LTAP in consultation with county personnel. Since WYDOT evaluates bridges, they were located only.

The data collectors observed each road surface distress while slowly driving each road segment. At the end of the segment, the various distresses, such as rutting and potholes, were rated and objective measurements were made. On a subsequent pass, the data collectors evaluated the other features. The training materials are included in the accompanying CD; photographs of various assets in different distress conditions excerpted from the training materials are shown in Appendix A.1; and the rated features and possible ratings and classifications are listed in Appendix A.2.

3.2.1 Gravel Road Ratings

Gravel road ratings were loosely based on the PASER road rating system *(Walker, 1989)* developed by the Wisconsin Transportation Information Center, using their gravel road rating manual. The manual rates roads from Excellent to Failed; the ratings are primarily driven by necessary maintenance activities.

Table 3.1 shows a brief summary of the rating standards used with the PASER road rating system for gravel roads. The PASER manual has an extensive list of visible distresses which aren't presented here.

Table 3.1 PASER gravel road overall rating standards (Walker 1989)

Rating	General Condition	Drainage	Maintenance
10 - Excellent	New construction or total reconstruction	Excellent drainage	Little or no maintenance needed
8 - Good	Recently regraded; Adequate gravel for traffic	Good crown and drainage throughout	Routine maintenance may be needed
6 - Fair	Shows traffic	Needs some ditch improvement and culvert maintenance	Regrading (reworking) necessary to maintain; Some areas may need additional gravel
4 - Poor	Travel at slow speeds (less than 25 mph) is required	Major ditch construction and culvert maintenance also required	Needs additional new aggregate
2 - Failed	Travel is difficult and road may be closed at times	Needs complete rebuilding and/or new culverts	

There are other systems and standards. One example, from Finland in the 1980s, is presented in Table 3.2. This Finnish system is fairly similar to the PASER system we used; both the system from Finland and the PASER system from Wisconsin are from climates wetter than Wyoming's. They expect less dust and washboards than we have to put up with in our arid climate. They focus more on drainage than we do. In wetter climates, long–term saturation of the base and subgrade is a road drainage system's primary objective; in Wyoming, drainage systems are as much about flash floods as long–term saturation. While the old belief that we don't need to worry much about drainage here is clearly false, Wyoming road drainage doesn't need to be as good as it does in wetter climates. By addressing flash flooding and clear zone issues, we are also solving base and subgrade saturation problems. Differing climates dictate some adjustment in how roads are evaluated; these adjustments to the system were addressed during our training sessions.

Table 3.2 Finnish gravel roads surface condition rating standards (Jäsmä 1983)

Rating	Condition
4.1 - 5.0	Road surface has maintained its shape and is very even and firm; possible unevenness of surface does not affect driving comfort.
3.1 - 4.0	Road surface has generally maintained its shape and is even and firm; some single holes here and there; no dust; running speed can be maintained in spite of unevenness.
2.1 - 3.0	Road surface has generally maintained its shape and is mostly even and firm; local small holes and unevenness; some dust; holes and uneven spots can be avoided, or they are such that the running speed can be maintained; in giving way to overtaking or oncoming vehicles a lower running speed should be used.
1.1 - 2.0	Shape of road cross section may have changed somewhat; some "washboard waves" on surface; local settlements or humps marked with traffic signs; moderate dust; lower running speed sometimes needed and uneven spots must be avoided.
0.1 - 1.0	Shape of road cross section has changed in several spots; surface is uneven due to holes, "washboard waves," and ravelings; settlements and humps on road that cannot be avoided; plenty of dust; road surface must constantly be watched and running speed changed often.

3.2.2 Asphalt Road Ratings

Asphalt segments, both those paved with hot mix asphalt and those with inverted penetration, chip seal, or other bituminous surface treatments. No distinction was made between the paved and sealed surfaces. Ratings were made based on the PASER manuals (Walker 1989).

3.2.3 Sign Ratings

Signs were located, measured, and evaluated. No nighttime or retroreflectivity information was collected. Size, type, and the legend were recorded and the panel and support conditions were recorded. Panels were rated as: excellent; faded, no gunshot holes; few gunshot holes; many gunshot holes; and illegible. Sign supports were also rated and their type recorded.

3.2.4 Culvert Ratings

Culverts were measured, their types recorded, and their condition and flow rated.

3.2.5 Cattleguard Ratings

Cattleguards were measured and the condition of the grate, base, wing fence, and approach were rated.

3.2.6 Approach Ratings

Approach type and location were recorded, as were the width and gate type.

3.2.7 Bridge Ratings

Bridges were located and comments were made. No ratings of bridges were conducted, in part because WYDOT inspects the bridges over 20 ft. long.

3.3 Objective Measurements

In addition to the subjective ratings described above, some aspects of the roadways were measured. In addition to the road surface measurements – crown slope and top width – numerous aspects of the other assets were recorded, such as culvert diameters, cattleguard sizes, and sign types. For a complete list of the measured and evaluated features, see the data dictionary in Appendix A.2.

Roadway top width was measured from the hinge of the traveled way and the shoulder, as described in (Skorseth and Selim 2000). Crown was measured by placing a four–foot level on a portion of the roadway with a representative cross slope and measuring the drop in four feet.

3.4 Data Quality Control

Efforts were made to insure consistent ratings from data collection team to team. After the teams had been collecting data for several days, the ratings trainer went out with the crews and rated road segments side by side, discussing the ratings for each segment in an effort to achieve consistent ratings by all data collection teams.

The ability of the different teams to rate roads about the same was tested by having the trainer and two teams rate the same segments at the same time. The ratings were compared upon return to the office.

3.5 Gravel Roads Performance Studies

In order to project the needs of the counties, it would be valuable to have information on the deterioration rates of gravel roads. Forty study segments at 20 locations, 10 in Carbon County and five each in Sheridan and Johnson counties were rated weekly. The results of this study are published elsewhere *(Weaver, Huntington, and Ksaibati, 2006; Huntington and Ksaibati, 2007;* see Appendix A.3).

3.6 Functional Classifications

T^2/LTAP, in conjunction with the counties, assigned a functional class to each road segment. In all three counties, all road segments were assigned to one of four functional classes: Resource, Local, Minor Collector, or Major Collector. (No asphalt roads were assigned to the Resource functional class.)

Functional classes are based primarily on traffic volumes. However, other factors, such as school bus routes, are also considered when assigning a road to a functional class.

There are various standards for establishing the functional classes of roads. The US Bureau of Land Management classifies its roads into Resource, Local, and Collector roads (USBLM 1982) in its standards. According to the BLM Standards, Resource roads have average daily traffic of 20 vehicles per day (vpd) or less; they "…are spur roads that provide point access and connect to local or collector roads. They carry very low volume and accommodate only one or two types of use." Local roads "…connect to collectors…receive lower volumes, carry fewer traffic types, and generally serve fewer uses. User cost, comfort, and travel time are secondary to construction and maintenance cost considerations." Local roads carry around 75 to 100 vpd, according to the BLM Standards. Collector roads "…provide primary access to large blocks of land, and connect with or are extensions of a public road system. Collector roads accommodate mixed traffic and serve many uses." Collector roads carry 50 to 150 vpd, again according to BLM Standards. Though traffic volumes are the primary variable separating different classes, connectivity and function also affect the assignment of a given road section to a particular functional class. Table 3.3 shows the approximate traffic volumes for each functional class, along with the assumed traffic volumes for the analyses described elsewhere in this report.

Table 3.3 Approximate and assumed traffic volumes by functional class in vehicles per day, vpd

Functional Class	**Approximate Traffic Volume, vpd**	**Assumed Traffic Volume, vpd**
Resource	0 - 20	5
Local	20 - 100	50
Minor Collector	100 - 250	150
Major Collector	250 - 750	400

3.7 Improvement Recommendations

The overall procedure for establishing the recommended improvements is similar for asphalt and gravel roads. For a detailed description of these procedures, see Appendices A.4 for gravel roads and A.5 for asphalt roads. Simpler procedures are used to recommend improvements for culverts, signs, and cattleguards. The current conditions are evaluated and, based on these evaluations, improvement recommendations are made. Figure 3.2 shows the overall process used to make recommendations.

For each road segment, potential improvements are recommended based on the current conditions. A user condition index is calculated, and those that are below the threshold value for their functional class are selected as candidates for improvement. Next, the appropriate improvement is selected based on the individual distress conditions. The benefit of these improvements is assessed by estimating the reduction in user costs resulting from performing the improvement. Those improvements that cost less than the reduction in user costs are recommended.

3.8 Construction and Routine Maintenance Needs

Annual costs are estimated based on estimated typical costs for each asset, with the road costs based on the surfacing type and the functional class of each segment. The procedures used for gravel roads are shown in Appendix A.6, while those for asphalt roads are shown in Appendix A.7. Figure 3.3 summarizes the process used to estimate the annual construction and routine maintenance costs.

3.9 Long–Term System Modeling

To estimate the effects of various spending levels on the long–term condition of the road systems, software modeling each county's gravel and asphalt roads was developed at T^2/LTAP. Visual Basic code was written that uses Excel as an input/output interface.

These models begin with the roads in their current condition. Highest priority maintenance is performed within the assumed budgetary constraints and the system condition is updated; this process is repeated through multiple iterations. Separate analyses are performed for paved and unpaved roads within each county. Paved asphalt, being a more durable surface that is maintained less frequently, is analyzed in one–year increments for a period of 40 years. Unpaved gravel roads, being less durable and requiring more frequent maintenance, is analyzed monthly for a period of 20 years.

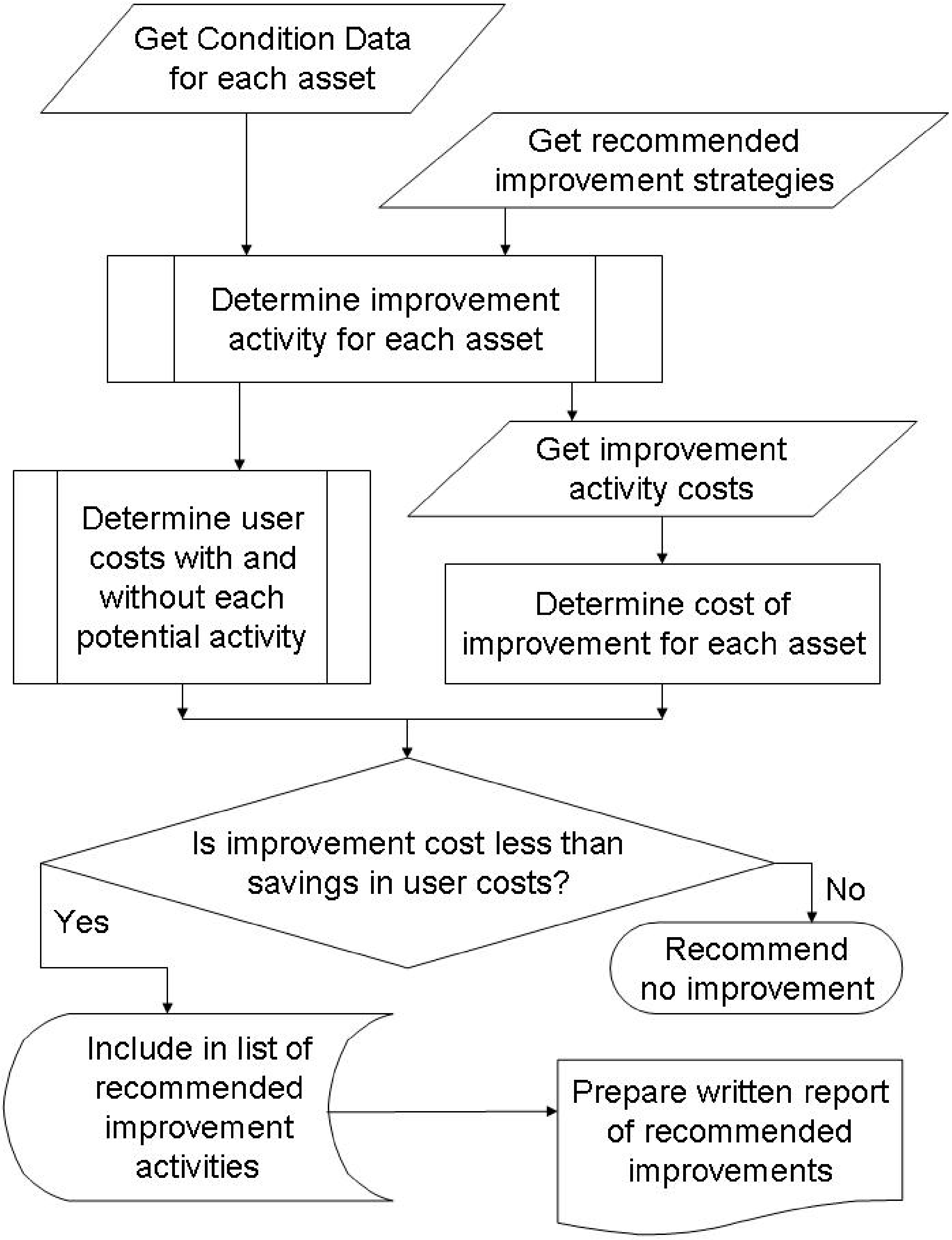

Figure 3.2 Overall improvement recommendation process.

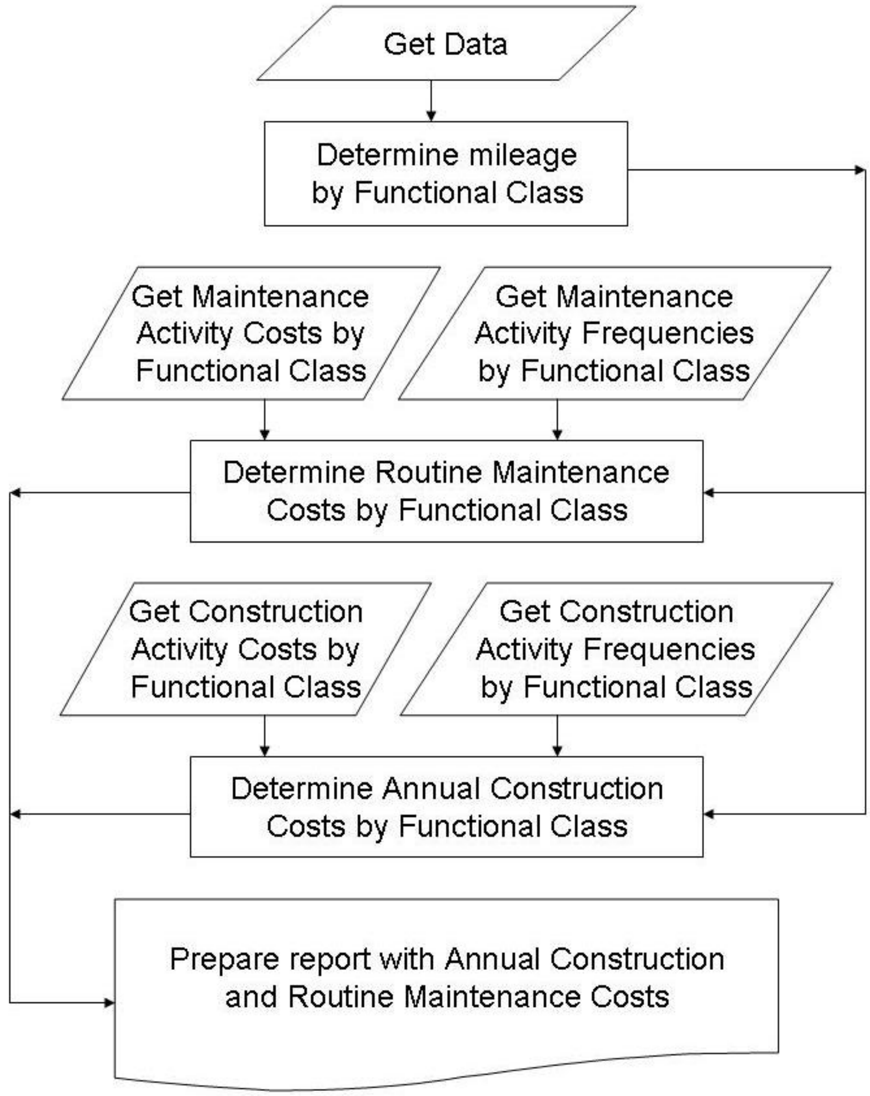

Figure 3.3 Annual routine costs estimating process.

3.10 Signs Assessments

For each sign assembly, the panel(s) were described and measured, the posts were rated and counted, and the sheeting condition was rated. Based on the observed conditions, repairs to existing signs are recommended. Routine repair and replacement costs are estimated based on the number of signs currently in place. Finally, desirable increases in the number of signs in each county are estimated.

Sign panels and sheeting were rated as being either “excellent,” “faded,” “few gunshot holes,” “many gunshot holes,” or “illegible.” Sign posts were rated as being either “okay and in place,” “bent or warped,” “no breakaway holes,” “broken,” or “missing.”

3.10.1 Sign Routine Maintenance and Replacement Costs

Repair and replacement costs for sign panels, sheeting, and posts are estimated, along with the typical life of a panel, sheeting, and post, as shown in Table 3.4.

Table 3.4 Sign repair and replacements costs and life of repairs

Activity	Cost	Unit	Repair Life, years
Replace Panel	$75	sf	21.0
Replace Post	$200	each	21.0
Replace Sheeting	$50	sf	10.5
Drill Breakaway Holes	$50	each	--

Table 3.4 assumes that sign sheeting is replaced every seven years, with the entire sign being replaced every 21 years. It is assumed that part of the cost of replacing the panel is replacing the sheeting, so panel costs are estimated at $25 per square foot, and sheeting costs are estimated at $50 per square foot.

3.10.2 Sign Improvement Recommendations

Sign sheeting replacement is recommended for “faded” or “few gunshot holes.” Panel replacement is recommended for “many gunshot holes” or “illegible.” The “bent or warped,” “broken,” and “missing” sign posts are recommended for replacement. Posts with 'no breakaway holes' are recommended for breakaway hole drilling. Costs of each of these activities are shown in Table 3.4.

3.10.3 Additional Sign Recommendations

In an effort to assess the number of signs on each county's road network, a desirable number of signs per mile for each functional class has been assumed: one sign every two miles for resource roads; one–and–a–half signs per mile for Local roads; two signs per mile for minor collector roads; and two–and–a–half signs per mile for major collector roads. From these values, the number of signs recommended for each functional class and county is recommended based on the mileage in each functional class and county; the cost of adding signs to each county's road network to reach these values is estimated. Using the costs from Table 3.4 and an assumed sign size of 24 in. x 24 in. (4 sf), the total cost per sign is estimated at $500.

3.11 Culverts Assessments

Every culvert, at least those that were found, was measured and the type was recorded. The condition and cleanliness of each culvert was rated. Cleanliness is an assessment of the portion of the culvert's cross–sectional area that is blocked by silt, debris, or other materials which lead to reduced flow. Based on these conditions, improvement recommendations are made. Based on the number and linear feet of culvert, annual cleaning, repair, and replacement costs are estimated.

3.11.1 Culvert Routine Cleaning, Repair, and Replacement Costs

The cost of cleaning, repairing, and replacing culverts is estimated, based on the size and length of the culvert, using the costs shown in Table 3.5 and the activity frequencies described as follows: Culverts are assumed to have a 50 year life, so 2% of all culverts are to be replaced each year; they are assumed to need repairs every 20 years so 5% of all culverts are repaired each year; and culverts are assumed to need cleaning once every seven years, so about 14% of the culverts are to be cleaned each year.

Table 3.5 Routine culvert repair, replacement, and cleaning costs

	Culvert Repairs, $/culvert	Culvert Replacement, $/lf	Cleaning, $/culvert
≤18"	$150	$75	$50
19" - 42"	$300	$100	$60
43" - 59"	$325	$150	$80
60" - 69"	$350	$200	$90
70" - 84"	$400	$300	$100
85" - 96"	$500	$400	$120
97" - 119"	$750	$500	$130
≥120"	$1,000	$750	$150

3.11.2 Culvert Improvement Recommendations

Culverts that are in sub–standard condition are recommended for improvements. Culverts that are in fair condition are recommended for repairs at the costs shown in Table 3.5; those in poor or failed condition are recommended for replacement, again using the cost per linear foot shown in Table 3.5.

Culverts that need to be cleaned are recommended for cleaning. Culverts with fair cleanliness ratings are cleaned at the costs listed in Table 3.5; those with poor cleanliness ratings are cleaned at twice the cost in Table 3.5; and those with failed cleanliness are cleaned at four times the cost in Table 3.5.

3.12 Cattleguard Assessments

Mainline cattleguards were evaluated and measured. The condition of the bases and grates was rated; the grate ratings were primarily focused on the potential for damage to tires as they cross the cattleguard. The cleanliness of the bases was also evaluated, with the primary criteria being the potential at present and in the near future for cattle getting across the guards.

3.12.1 Cattleguard Improvement Costs

Those cattleguards rated poor or failed are recommended for improvement. Grate conditions of poor or failed are recommended for grate replacement; base conditions of poor or failed are recommended for base replacement; and those with poor or failed cleanliness are recommended for cleaning, all at the costs shown in Table 3.6.

Table 3.6 Cattleguard replacement and cleaning costs

Grate Replacement	Base Replacement	Cleaning Base
$1,500	$5,000	$500

3.12.2 Cattleguard Annual Replacement and Cleaning Costs

Based on the total number of cattleguards, the cost of cleaning and replacing them from Table 3.6, and the cleaning and replacement frequencies in Table 3.7, the annual routine costs of maintaining each county's cattleguards has been estimated.

Table 3.7 Cattleguard cleaning and replacement frequency

Maintenance Activity	Years
Replace Base and Grate	25
Clean Out Base	10

4. RESULTS

A number of maps are included in this report. To view additional maps, see the CD prepared as part of this report. To have flexibility in the format and area viewed, open the maps in ArcMap or other ESRI GIS viewing software. If this software is not available, many maps are also stored in .jpg format.

4.1 System Summary

4.1.1 System Mileage and Value

Each county's road mileages by functional class are presented in Figures 4.1 and 4.2 for unpaved and oiled roads, respectively. The total reconstruction costs for each county's roads – the total value of the counties' network if they were rebuilt to current standards from scratch – are estimated in Table 4.1, based on the reconstruction costs from Tables A.4c and A.5d (see Volume III, Appendices A.4 and A.5) and the mileages from Figures 4.1 and 4.2. It is clear from Table 4.1 that the three counties included in this study have made a significant investment in their roads. Such an investment can be preserved by applying the required maintenance in a timely manner.

Table 4.1 Road system replacement costs

		Resource	Local	Minor Collector	Major Collector	TOTAL
Carbon	*Asphalt*	--	$5,325,898	$15,210,649	$70,325,437	$90,861,984
	Gravel	$83,468,431	$224,606,204	$280,793,602	$131,313,407	$720,181,644
	TOTAL	$83,468,431	$229,932,102	$296,004,251	$201,638,845	$811,043,628
Johnson	*Asphalt*	--	$2,858,802	$54,491,082	$67,282,840	$124,632,724
	Gravel	$14,312,367	$133,083,777	$222,198,811	$40,787,929	$410,382,884
	TOTAL	$14,312,367	$135,942,580	$276,689,893	$108,070,768	$535,015,608
Sheridan	*Asphalt*	--	$4,682,142	$19,504,296	$12,390,985	$36,577,423
	Gravel	$28,308,122	$141,134,559	$214,918,439	$29,425,280	$413,786,400
	TOTAL	$28,308,122	$145,816,701	$234,422,735	$41,816,265	$450,363,823

4.1.2 Unpaved/Gravel Roads

All unpaved roads were classified as gravel regardless of whether they are surfaced with imported gravel or native dirt. Dirt roads, those without imported gravel and those that have not been adequately maintained with routine gravel additions, are usually classified as resource roads. Roads with added reclaimed asphalt pavement (RAP) were also classified as gravel roads, as long as no additional oil was placed to create a hard surface. Though the distinction between gravel and asphalt roads is sometimes unclear, generally gravel roads' top surfaces can be reshaped with a motor grader's blade, while asphalt roads' surfaces cannot be easily reshaped.

The majority of gravel roads in the three counties are split about evenly between local and minor collector roads. Carbon County has a significantly higher portion of resource roads, those roads that generally receive the least use. Major Collector roads have less mileage, though their significance should not be underestimated since these roads generally carry the most traffic. Figure 4.3 maps Sheridan County's roads by functional classification.

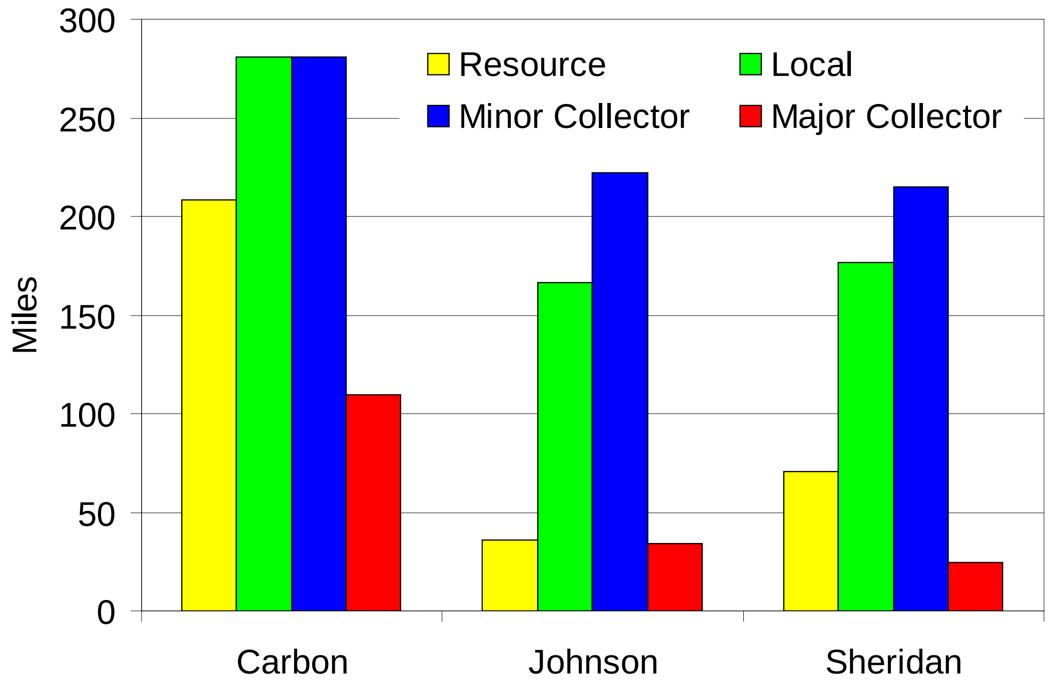

Figure 4.1 Gravel road mileages by functional class.

4.1.3 Oiled/Asphalt Roads

All roads with asphalt surfacing, whether that surface is hot mix asphalt or simply oil applied to the gravel base, are classified as asphalt roads. Generally, asphalt roads are those that cannot be worked or reshaped with a motor grader's blade.

All three counties have very little mileage of asphalt roads classified as local. Most local roads in the county are gravel rather than asphalt. Carbon County has a high portion of asphalt roads classified as major collector, though about 35 of the 54 miles of major collector asphalt roads in Carbon County are the Seminoe Road. Johnson County has nearly 35 miles of industrial asphalt roads. These roads are particularly vulnerable since they generally don't have enough structural strength to carry heavy drilling traffic.

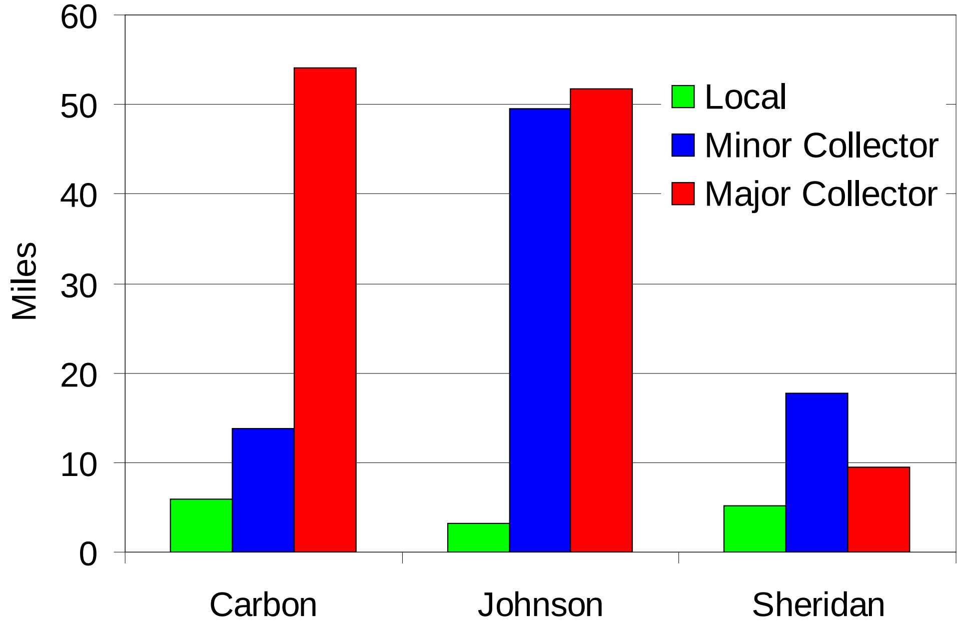

Figure 4.2 Asphalt road mileages by functional class.

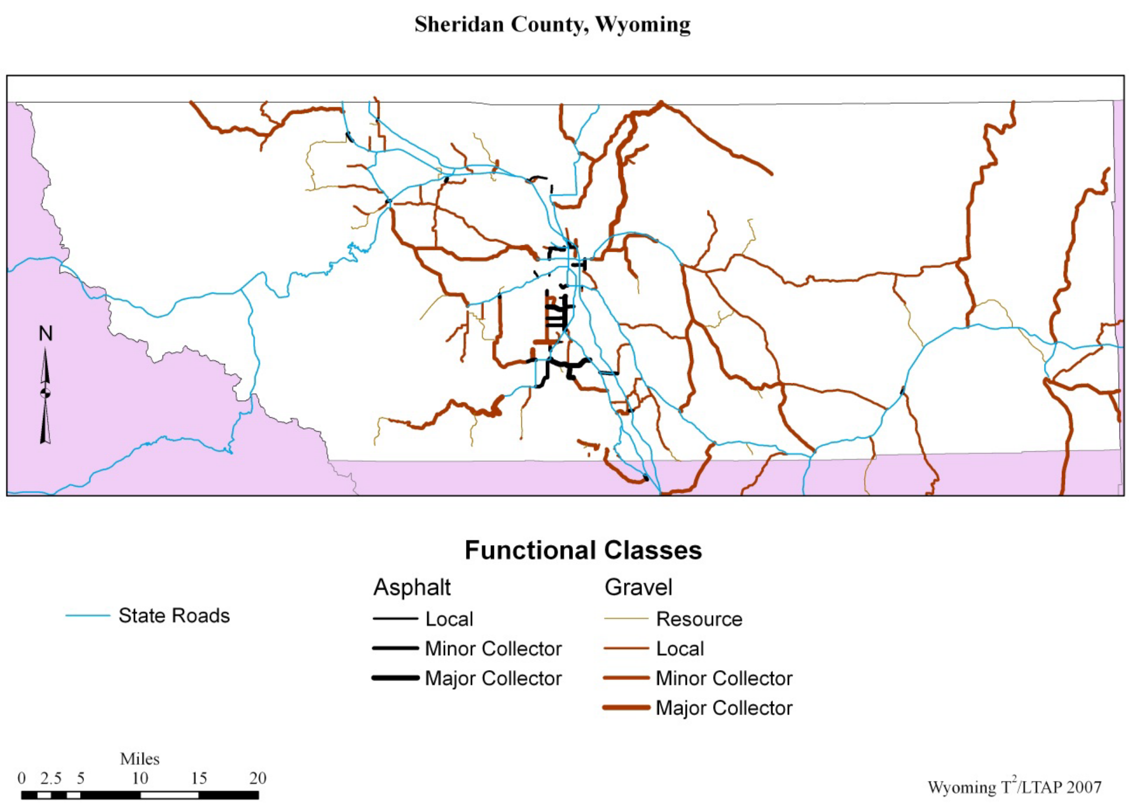

Figure 4.3 Sheridan County roads by functional classification.

4.1.4 Road and Other Asset Ratings

The simplest outputs from this asset management system are the raw condition ratings. These may easily be expressed as graphs, tables, or maps which can be generated from the data on the accompanying CD. A few examples are found in Figures 4.4, 4.5, and 4.6, which show Sheridan County's pothole ratings, Johnson County's washboard ratings, and Carbon County's dust ratings, respectively.

4.2 Gravel Roads Assessments

4.2.1 Gravel Roads Recommended Improvements

Recommended improvements to gravel roads are based on the road condition ratings performed as part of this program. They are also based on estimates of the cost of repairs and the condition levels at which improvements should be undertaken on roads in the different functional classes. Table 4.2 contains the total improvements costs at three different condition levels: minimal, recommended, and optimal (as described in Volume III, Appendix A.4, Table A.4a). Minor improvements include those that improve the road's surface or maintain the road's drainage characteristics: maintaining, spot maintenance, dust suppressant, regraveling, cleaning ditches, and reshaping ditches. Major improvements include those improvements that include realignments, significant structural improvements, or both: spot repairs, rehabilitation, and reconstruction. Figure 4.7shows the recommended improvement activities for Sheridan County.

Tables A.10a, A.10c, and A.10e (see Volume III, Appendix A.10) contain the road–by–road improvements recommended for gravel roads in the three counties. Tables A.10b, A.10d, and A.10f (see Volume III, Appendix A.10) contain the estimated cost of recommended improvements to gravel roads for each county by functional class and maintenance activity. The total miles to which the recommended improvement activities should be applied are also included.

Maintaining road segments is not recommended for any of the segments in the three counties, largely because simply maintaining a road will not bring about the desired improvements. Routine maintenance on gravel roads should be performed on an on–going basis.

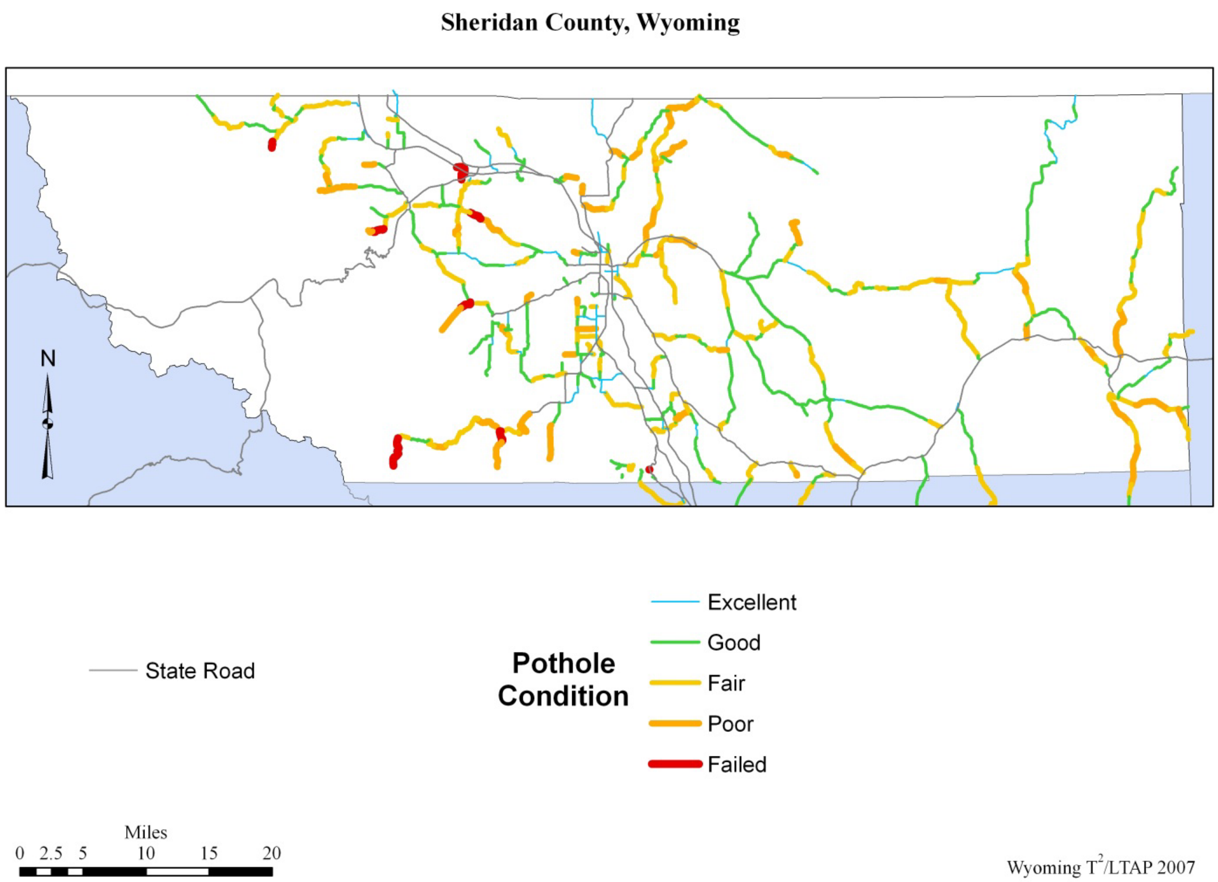

Figure 4.4 Sheridan County pothole ratings.

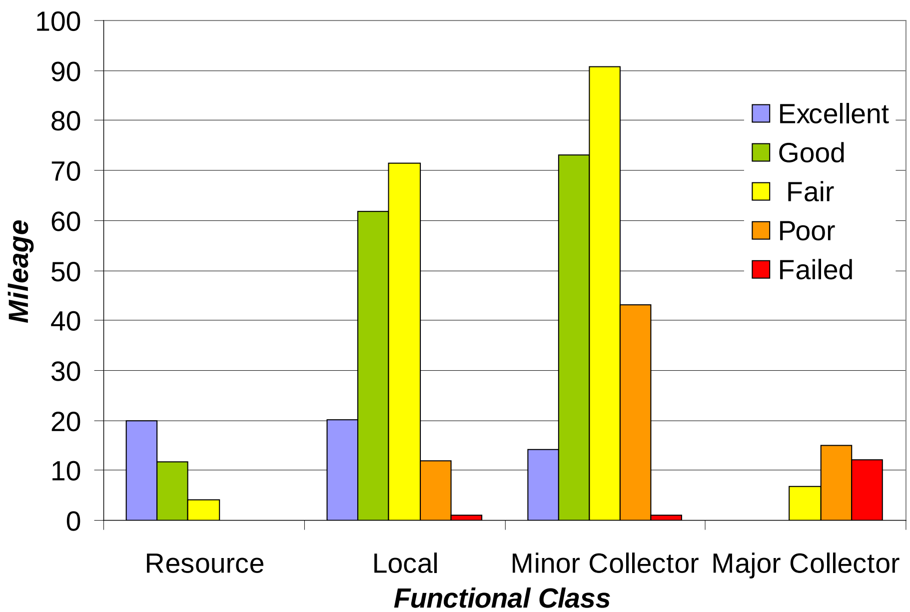

Figure 4.5 Johnson County washboard ratings.

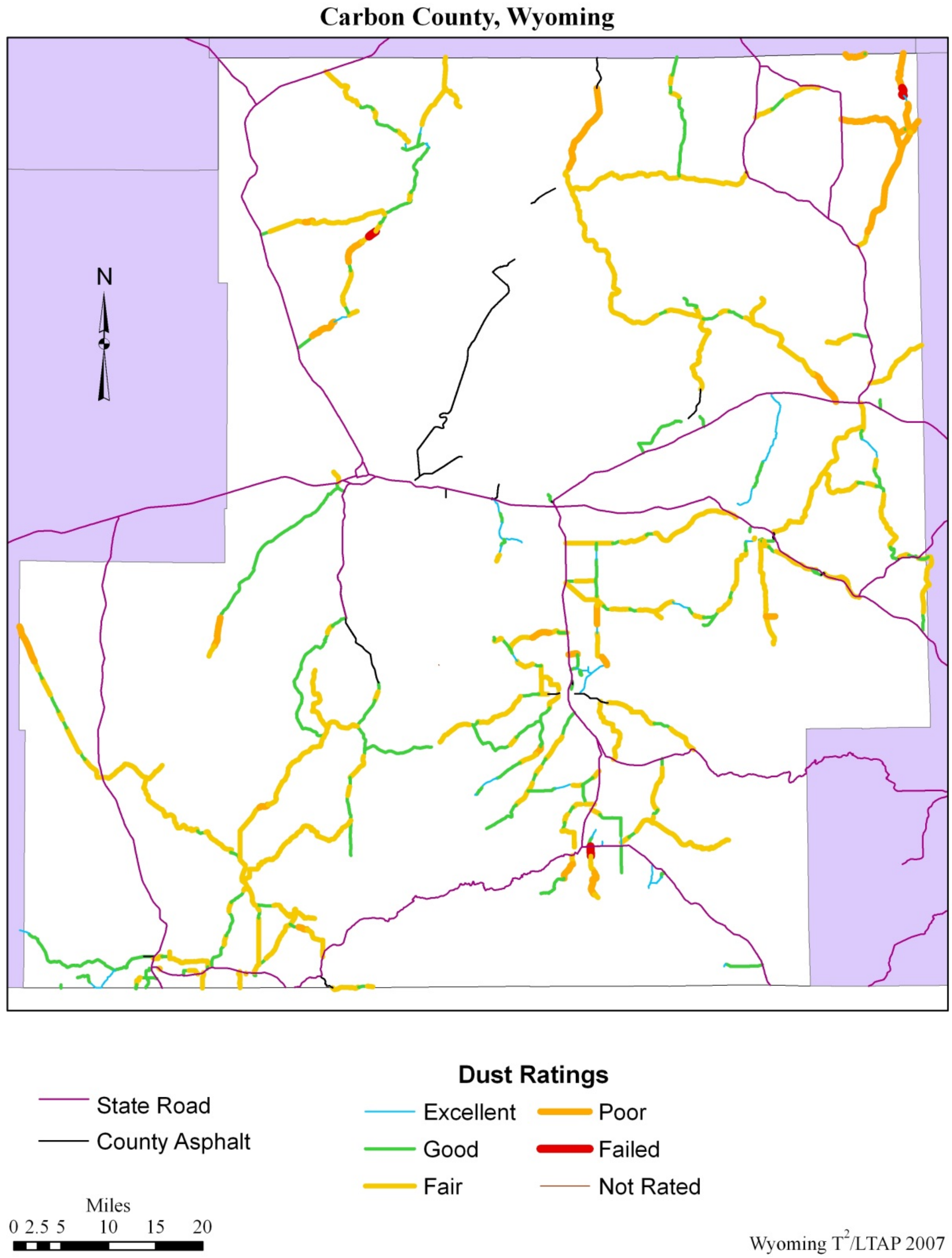

Figure 4.6 Carbon County dust ratings.

Table 4.2 Gravel roads recommended improvement costs at various condition levels

	Minor Improvements		
	Minimal	*Recommended*	*Optimal*
Carbon	$46,830	$301,501	$775,248
Johnson	$244,421	$631,374	$1,541,066
Sheridan	$279,819	$522,934	$1,405,673
	Major Improvements		
	Minimal	*Recommended*	*Optimal*
Carbon	$740,454	$1,612,173	$1,748,038
Johnson	$332,409	$746,745	$796,558
Sheridan	$1,562,842	$2,962,980	$3,034,525
	Total Improvements		
	Minimal	*Recommended*	*Optimal*
Carbon	$787,285	$1,913,675	$2,523,285
Johnson	$576,831	$1,378,118	$2,337,623
Sheridan	$1,842,661	$3,485,914	$4,440,198

Reconstruction is not recommended above for any gravel road segment in the three counties. This is not because there aren't any roads that need to be reconstructed. It is simply because none of the roads fell into a category in Table A.4b (see Volume III, Appendix A.4) that would recommend reconstruction using this surface condition analysis. Reconstruction would only be recommended by this analysis in extreme cases where a high volume road failed due to potholes or rutting. It is a credit to the three counties' road and bridge crews that they have been able to use stop–gap measures to prevent such failures. Typically, reconstruction is driven by excessive maintenance costs, geometric deficiencies, or both. The analysis described above does not address either of these problems. However, the following section contains estimates of these reconstruction needs.

4.2.2 Gravel Roads Construction and Routine Maintenance

Estimates of the annual construction and maintenance needs were made for each county using the methods described in section 3.8 and are shown in Table 4.3 (see Volume III, Appendix A.12, Tables A.12a, A.12b, and A.12c for detailed summaries).

Table 4.3 Gravel roads estimated annual construction and routine maintenance costs

	Carbon	*Johnson*	*Sheridan*
Maintenance	$3,603,851	$2,164,256	$2,069,765
Construction	$2,294,915	$1,371,691	$1,298,836
Total	$5,898,766	$3,535,947	$3,368,602

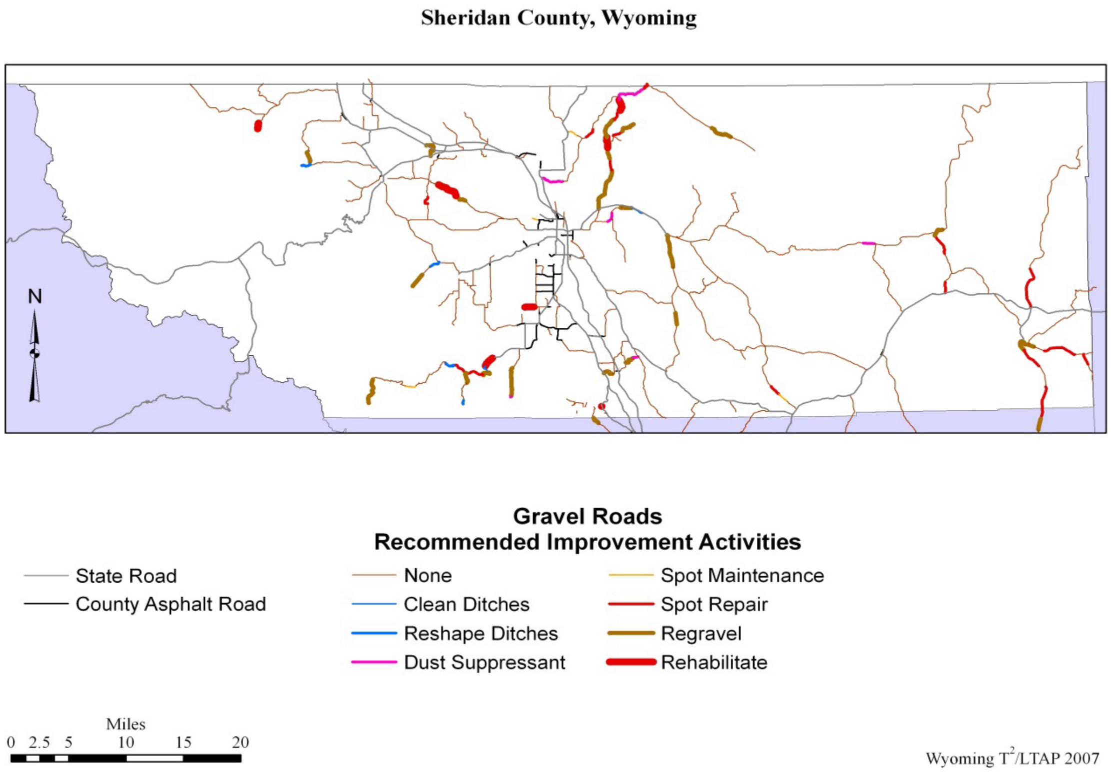

Figure 4.7 Sheridan County gravel roads recommended improvement activities.

If the counties' gravel roads were in ideal condition, major repairs and reconstruction would not be necessary. However, this is the real world and conditions are not ideal – no road is perfectly smooth and perfectly safe. There are roads in all three counties that would significantly benefit from improvements, either structural, functional, or both. T^2/LTAP estimates that it would take funding construction activities at the rates shown in Table 4.3 for five to 15 years to get the counties' systems in recommended conditions, after which funding at the routine maintenance levels would be sufficient to maintain the counties' road systems. However, any changes to the counties' systems, due either to the construction or adoption of new roads or to increased usage on some county roads, would necessitate additional funding increases.

4.3 Asphalt Roads Assessments

4.3.1 Asphalt Roads Recommended Improvements

Recommended improvements to asphalt roads are based on the road condition ratings performed as part of this program, using the procedures described in Section 3.7 and Volume III, Appendix A.5. Table 4.4 contains the total recommended improvements split into three categories: seal coats, overlays, and major improvements (rehabilitation and reconstruction).

Table 4.4 Recommended asphalt roads improvements by county and type

	Carbon	Johnson	Sheridan
Seal Coats	$196,055	$0	$0
Overlays	$240,640	$2,976,290	$691,240
Major Improvements	$547,250	$41,736,000	$0
TOTAL	$983,945	$44,712,290	$691,240

Recommended major improvements – reconstruction, rehabilitation, and overlays – on a road–by–road basis are presented in Volume III, Appendix A.11, Tables A.11b, A.11d, and A.11f. Johnson County has substantially more recommended improvements than Sheridan or Carbon County. This is due to several factors; first, Johnson County has more oiled roads, 104 miles, than Sheridan with 32 miles or Carbon with 74 miles. Of Carbon's 74 oiled miles, 34 miles are the Seminoe Road, which was recently reconstructed. Twenty–two miles of Johnson County roads are recommended for reconstruction, while none are recommended for Sheridan or Carbon counties. For overlays and minor improvements, the difference in miles accounts for the discrepancies in recommended improvements. However, the difference in funding for major improvements to Johnson County's asphalt roads is due to several roads which are recommended for reconstruction (see Volume III, Appendix A.11, Table A.11d), primarily Trabing and Irigaray roads, which have a total of $35 million in recommended repairs on 25 miles of roads. These roads are structurally insufficient, with several layers of chip seal on top of a thin gravel base.

Table A.11a in Volume III, Appendix A.11 shows the recommended improvements at minimal, recommended, and optimal improvement levels. Figure 4.8 shows the recommended improvement costs per mile in Johnson County.

Tables A.11c, A.11e, and A.11g in Volume III, Appendix A.11 show the recommended major improvement activities and the mileage to which they should be applied for Carbon, Johnson, and Sheridan Counties, respectively. The costs in these tables should be considered order–of–magnitude starting points when assessing the needs on an individual road. The asset management program is an analytical tool, not a decision maker.

4.3.2 Asphalt Roads Construction and Routine Maintenance

Estimates of the annual construction and maintenance needs were made for each county using the methods described in Section 3.8 and Volume III, Appendix A.7; they are summarized in Table 4.5. Appendix A.13 in Volume III contains the annual costs by functional class and maintenance or construction activity.

Table 4.5 Annual asphalt roads construction and routine maintenance costs

	Routine Maintenance Costs	Annual Overlay Costs	Annual Construction Costs	Total Annual Costs	Total Miles
Carbon	$335,260	$219,714	$355,629	$910,602	74
Johnson	$456,022	$300,561	$462,577	$1,219,161	105
Sheridan	$129,587	$85,962	$118,785	$334,335	32

These costs are based strictly on expected long–term maintenance and reconstruction costs to keep the current system in acceptable condition. The cost for major improvements is conservative estimates of the annual reconstruction costs that should be incurred over the years to keep the road network in desirable conditions. These figures do not anticipate such inevitable occurrences as adding new roads to the system or significant traffic increases.

The three counties have unique characteristics that may influence the actual annual costs incurred on their asphalt roads. Costs for Carbon County are likely to be lower than those presented in Table 4.5 since about half the mileage is Seminoe Road, which was recently reconstructed. Conversely, Johnson County's costs are likely to be higher since much of the mileage is not paved roads, but roads that are structurally insufficient with chip seal surfaces, as described in Section 4.3.1.

4.4 Signs Assessments

4.4.1 Sign Conditions

4.4.1.1 Sign Panel and Sheeting Conditions

The ratings of the sign panels are presented in Figure 4.9, based on the square footage of panels in each condition.

4.4.1.2 Sign Post Conditions

The condition of the sign posts are presented in Figure 4.10.

4.4.2 Sign Routine Maintenance Costs

Based on the existing sign panel square footage and number of sign supports, annual maintenance and replacement costs are estimated using the values in Table 3.4, as shown in Table 4.6.

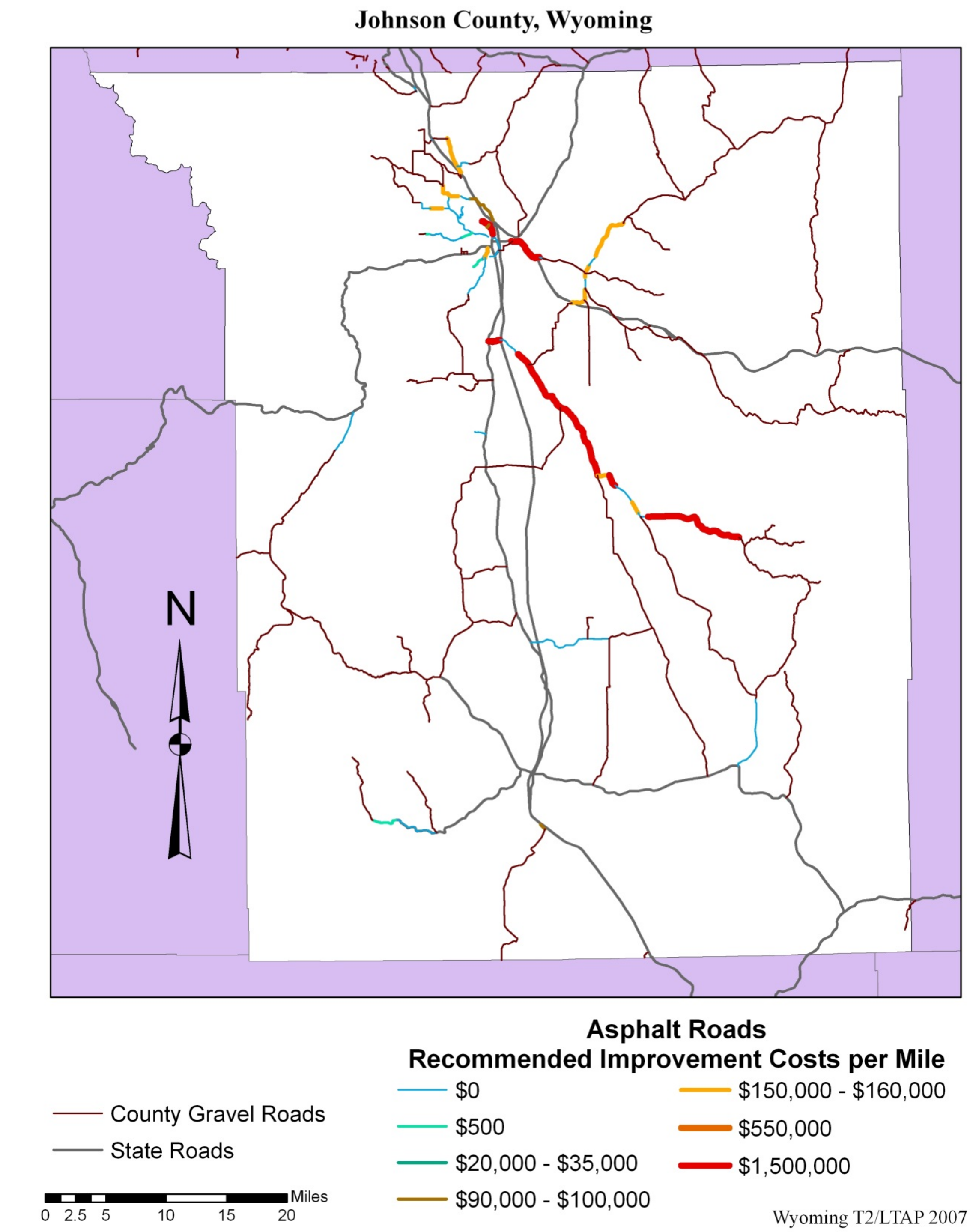

Figure 4.8 Johnson County asphalt roads recommended improvement costs per mile.

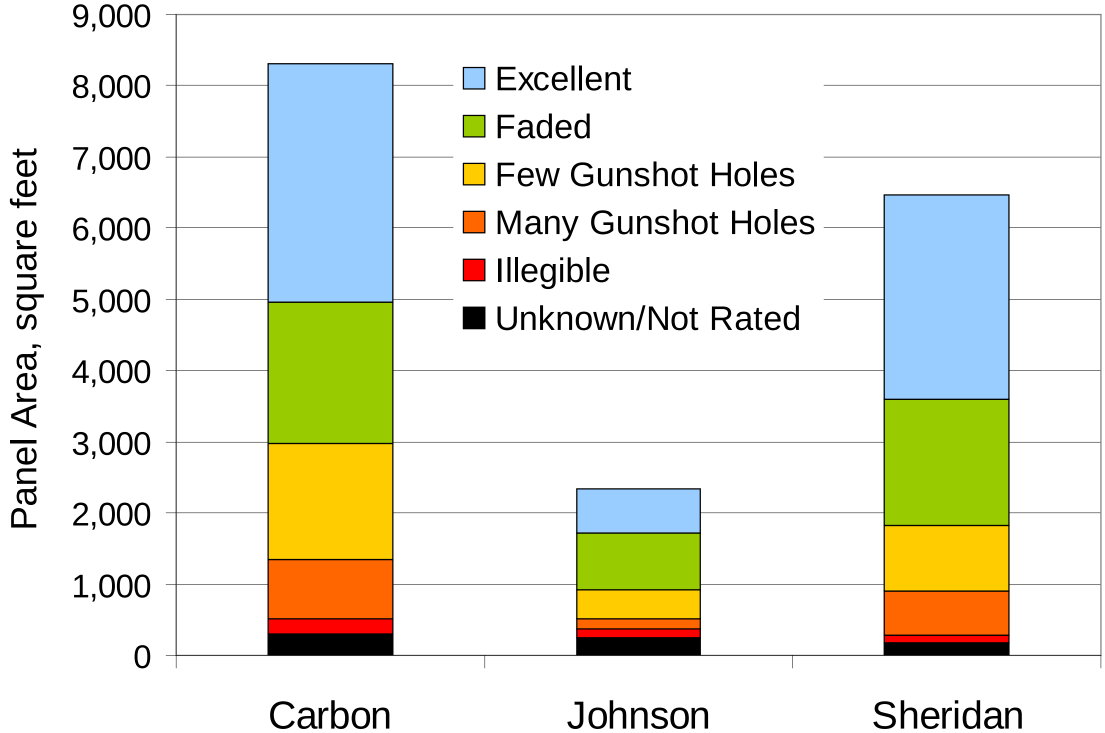

Figure 4.9 Sign panel and sheeting conditions.

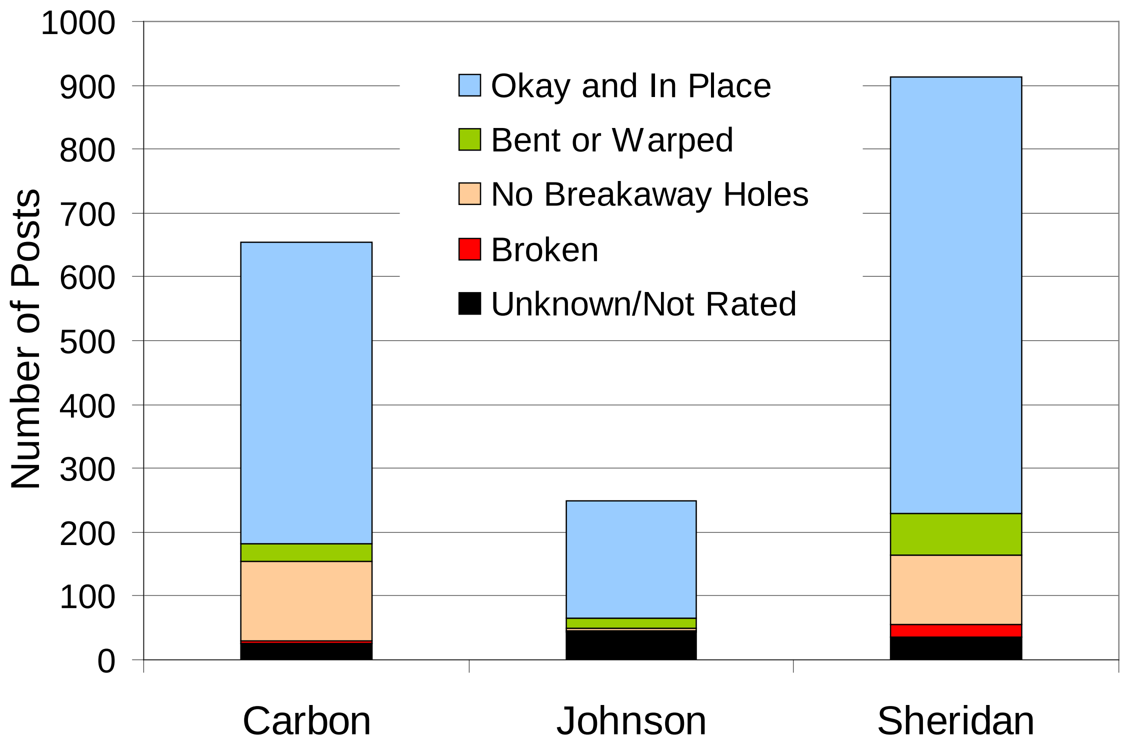

Figure 4.10 Sign post conditions by number of supports.

Table 4.6 Routine repair and replacement costs for existing signs

	Panel Replacement		Sheeting Replacement		Support Replacement		Total Cost
	ft^2	Cost	ft^2	Cost	No.	Cost	
Carbon	396.0	$29,703	792.1	$39,604	32	$6,429	$75,735
Johnson	110.9	$8,317	221.8	$11,089	12	$2,381	$21,787
Sheridan	307.6	$23,074	615.3	$30,765	42	$8,400	$62,238

If the additional signs are installed as recommended in Section 4.4.4, these signs will also need to be maintained. The annual cost of maintaining both the existing and additional signs is shown in Table 4.7.

Table 4.7 Routine annual cost of maintaining existing and recommended additional signs

	Annual Cost of Maintaining Existing Signs	Annual Cost of Maintaining Additional Signs	TOTAL
Carbon	$75,735	$21,010	$96,745
Johnson	$21,787	$19,643	$41,430
Sheridan	$62,238	$1,850	$64,088

4.4.3 Sign Improvement Recommendations

Based on the current sign panel and post conditions and the procedures in Section 3.10.2, improvements are recommended as summarized in Table 4.8.

4.4.4 Additional Signs

When assessing these additional sign recommendations, one should consider that different roads have different signing needs beyond the different signing rates recommended for the road's functional class. Curves, limited sight distance, intersections, and other structural and functional characteristics all affect the number of signs needed on a given section of road. Table 4.9 shows the average signs per mile for each county and functional class, along with the target signs per mile for each class. Based upon the assumed frequency of signs described in Section 3.10.3, additional signs are recommended by county and functional class as presented in Table 4.10.

It should be noted that these are only estimates based on the mileage by functional class, not on the specific signing needs for each county's road network. Factors such as traffic types, traffic volumes, and roadway geometry will affect the signs needed on any particular road.

Table 4.8 Recommended sign improvement costs

Sign Panel Condition	Faded or Few gunshot holes		Many gunshot holes or Illegible		
Recommended Action	*Replace Sheeting*		*Replace Panel*		*Total Panel Cost*
	ft^2	*Cost*	*ft^2*	*Cost*	
Carbon	3591.7	$179,585	1083.8	$81,282	$260,867
Johnson	1220.3	$61,016	259.5	$19,459	$80,476
Sheridan	2698.7	$134,933	743.4	$55,753	$190,685

Sign Post Condition	No breakaway holes		Broken, missing, bent or warped		*Total Supports Cost*
Recommended Action	*Drill breakaway holes*		*Replace support*		
	No.	*Cost*	*No.*	*Cost*	
Carbon	126	$6,300	30	$6,000	$12,300
Johnson	4	$200	18	$3,600	$3,800
Sheridan	108	$5,400	86	$17,200	$22,600

Total Sign Upgrade Costs	
Carbon	$273,167
Johnson	$84,276
Sheridan	$213,285

Table 4.9 Signs per mile by functional class on each county's system and target signs per mile

	Resource	*Local*	*Minor Collector*	*Major Collector*
Carbon	0.25	0.80	0.72	0.96
Johnson	0.06	0.32	0.43	0.37
Sheridan	0.48	1.58	1.67	4.93
Target	*0.5*	*1.5*	*2.0*	*2.5*

Table 4.10 Recommended additional sign expenditures

	Resource	*Local*	*Minor Collector*	*Major Collector*	*TOTAL*
Carbon	$26,168	$100,507	$188,621	$125,905	$441,201
Johnson	$7,945	$99,648	$213,736	$91,182	$412,512
Sheridan	$693	$0	$38,150	$0	$38,842

4.5 Culverts Assessments

Culverts, particularly small ones, are often difficult to find. Table 4.11 shows the number and length of culverts found in each county by size.

Table 4.11 Number and length of culverts in each county by size

Culvert Sizes	Number			Length, ft		
	Carbon	Johnson	Sheridan	Carbon	Johnson	Sheridan
≤18"	688	1,001	1,264	25,498	39,217	49,474
19" - 42"	641	557	610	30,914	25,597	28,458
43" - 59"	64	86	73	4,158	4,432	4,130
60" - 69"	47	19	39	3,539	792	2,203
70" - 84"	28	45	63	2,493	2,425	3,593
85" - 96"	3	9	14	208	453	961
97" - 119"	6	1	2	630	60	110
≥120"	15	3	17	1,266	194	1,013
TOTAL	1,492	1,721	2,082	68,706	73,170	89,942

4.5.1 Culvert Conditions

The condition of the culverts was rated. Figures 4.11, 4.12, and 4.13 show the condition of culverts by size in each county.

4.5.2 Culvert Flow/Cleanliness

The flow (cleanliness) of the culverts was rated. Figures 4.14, 4.15, and 4.16 show the flow of culverts by size in each county. Figure 4.17 maps the flow of culverts near Buffalo in Johnson County.

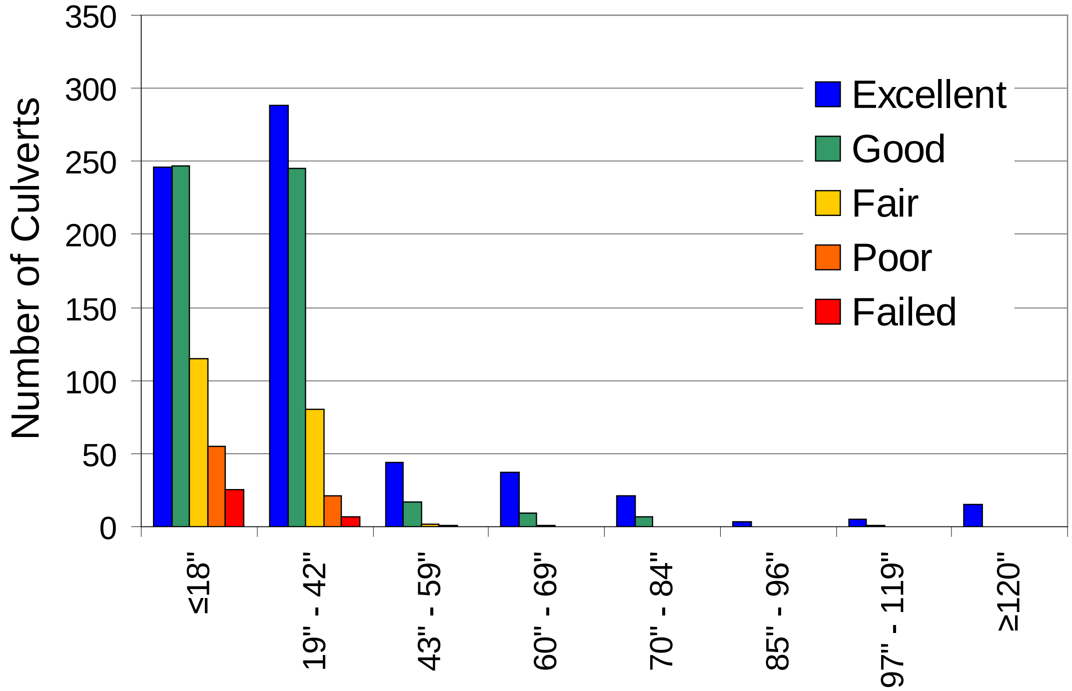

Figure 4.11 Carbon County culvert conditions by size.

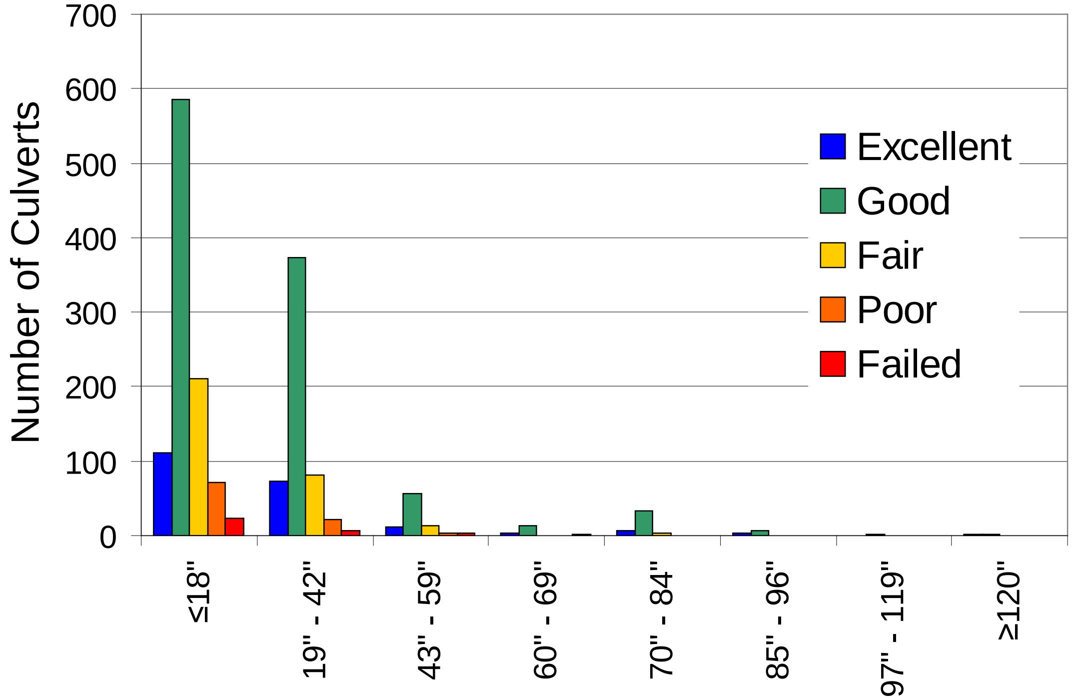

Figure 4.12 Johnson County culvert conditions by size.

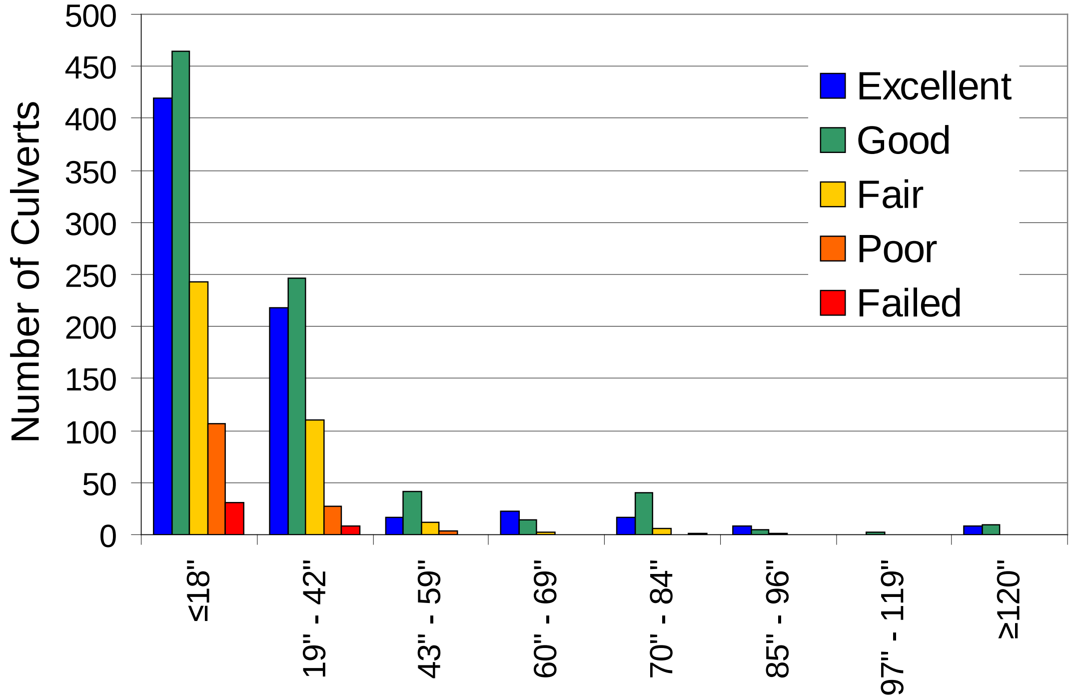

Figure 4.13 Sheridan County culvert conditions by size.

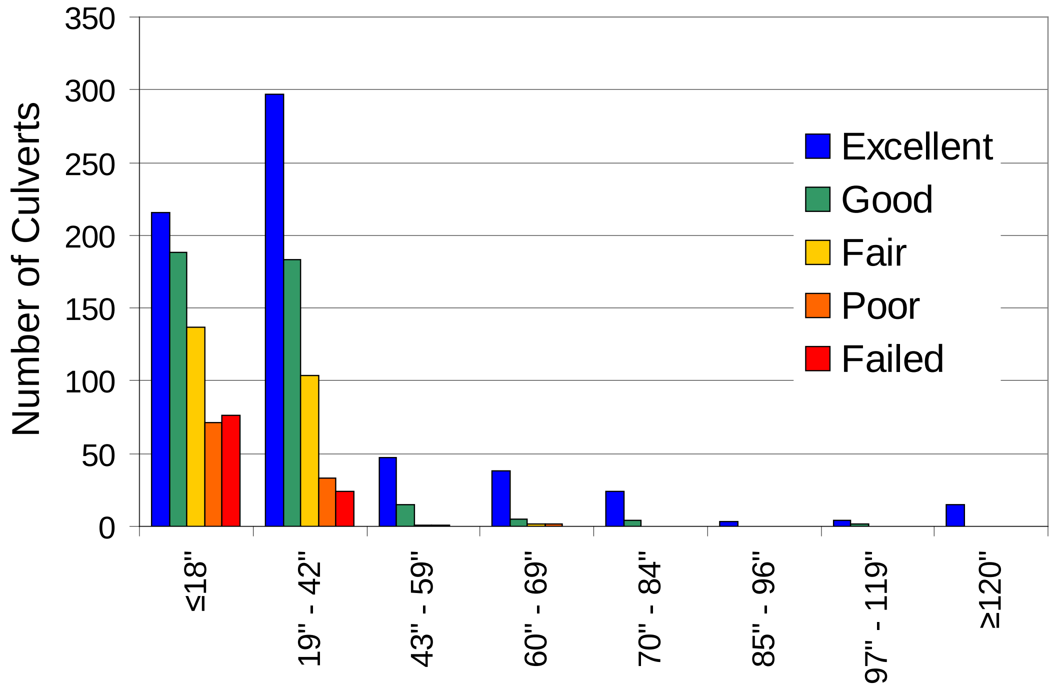

Figure 4.14 Carbon County culvert flow/cleanliness by size.

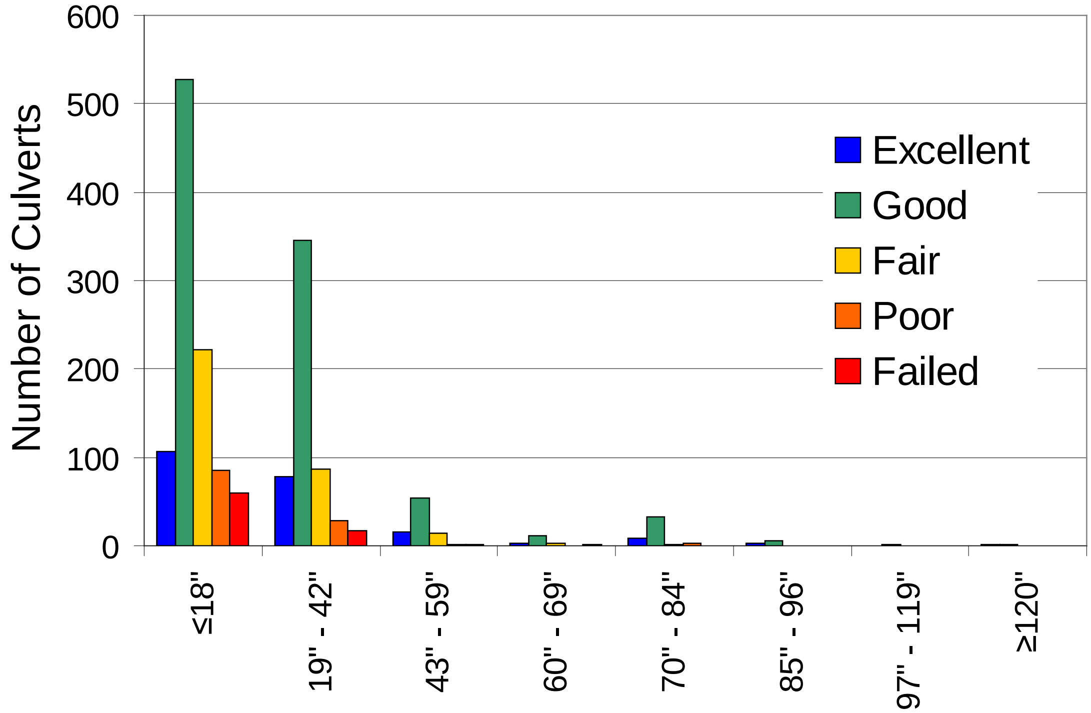

Figure 4.15 Johnson County culvert flow/cleanliness by size.

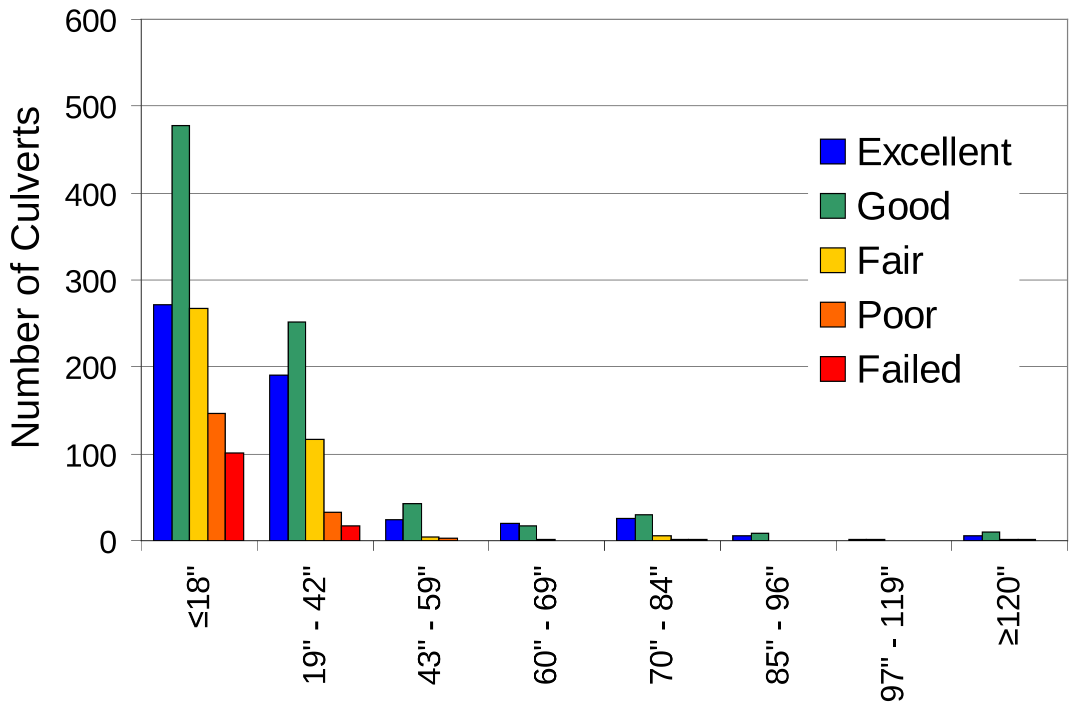

Figure 4.16 Sheridan County culvert flow/cleanliness by size.

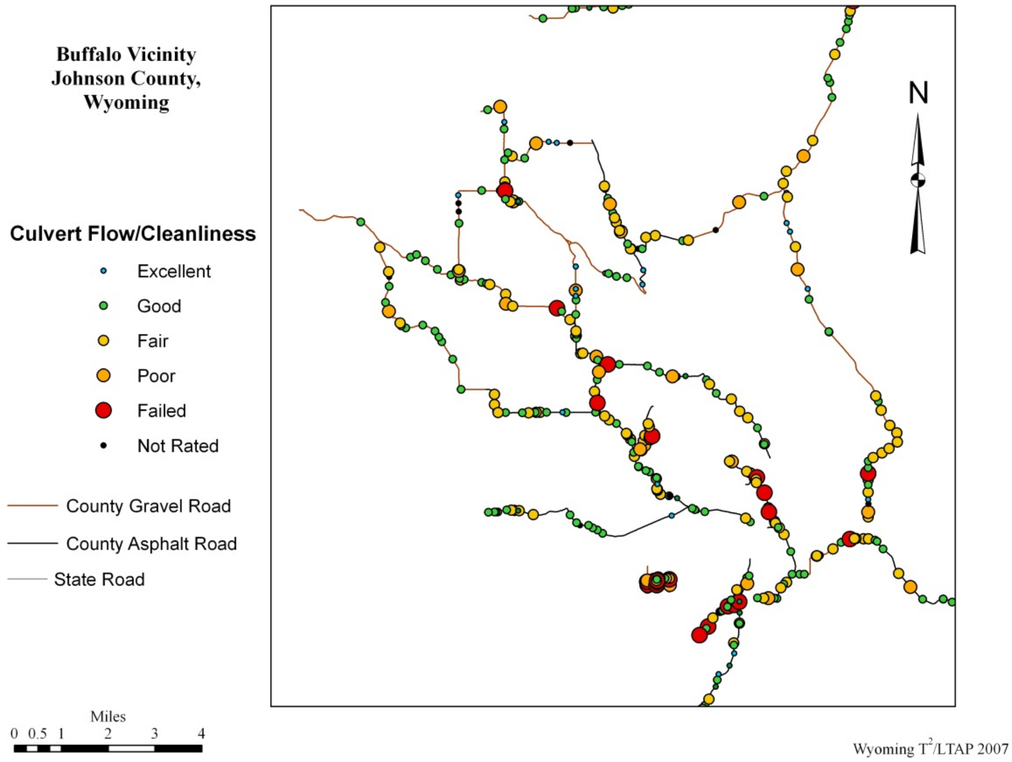

Figure 4.17 Culvert flow/cleanliness near Buffalo, Johnson County.

4.5.3 Recommended Culvert Improvements

Based on their current condition and cleanliness and the costs in Table 3.5, recommended improvements to each county's culverts have been made as described in Volume III, Appendix A.14 and summarized in Table 4.12.

Table 4.12 Culvert recommended improvement costs

	Repair Costs	Replacement Costs	Cleaning Costs	Total Costs
Carbon	$42,250	$298,850	$66,850	$407,950
Johnson	$61,775	$454,150	$64,710	$580,635
Sheridan	$76,950	$568,100	$90,670	$735,720

It should be kept in mind that these improvements only apply to the culverts in place; this analysis does not address the issue of whether there are enough culverts. Also, this analysis does not address the issues associated with the sizing or type of culverts or whether or not they are appropriate for their location. A third factor not considered is whether the culverts are properly placed. Some placement issues will be reflected by damage or clogging of the culverts, resulting in low condition or cleanliness ratings. However, some placement issues, such as whether a culvert will be prone to washouts during a flash flood, may not be apparent from the ratings. Thus, if all needed improvements to culverts in each county are included, the costs shown in Table 4.12 would be higher.

4.5.4 Annual Culvert Replacement and Maintenance Costs

Based on the number, length, and size of culverts shown in Table 4.11 and using the procedures described in Section 3.11.1 the annual cost of maintaining each county's culverts in their current condition is estimated in Table 4.13, with details presented in Volume III, Appendix A.15.

Table 4.13 Annual culvert replacement and maintenance costs

	Replacements	Repairs	Cleaning	TOTAL
Carbon	$168,617	$18,248	$12,629	$199,493
Johnson	$148,168	$18,905	$14,031	$181,104
Sheridan	$197,870	$23,034	$17,134	$238,038

4.6 Cattleguards Assessments

Mainline cattleguards were counted and rated in each county. Table 4.14 shows the number of cattleguards counted in each county, by length.

Table 4.14 Mainline cattleguard counts by length and county

Length, ft	Carbon	Johnson	Sheridan
8' - 13'	75	60	29
14' - 17'	57	70	31
18' - 23'	72	113	26
24'	264	56	60
25' - 40'	27	15	13
TOTAL	495	314	159

4.6.1 Cattleguard Conditions and Base Cleanliness

The grate and base conditions for all rated mainline cattleguards are shown in Figures 4.19, 4.20, and 4.21.

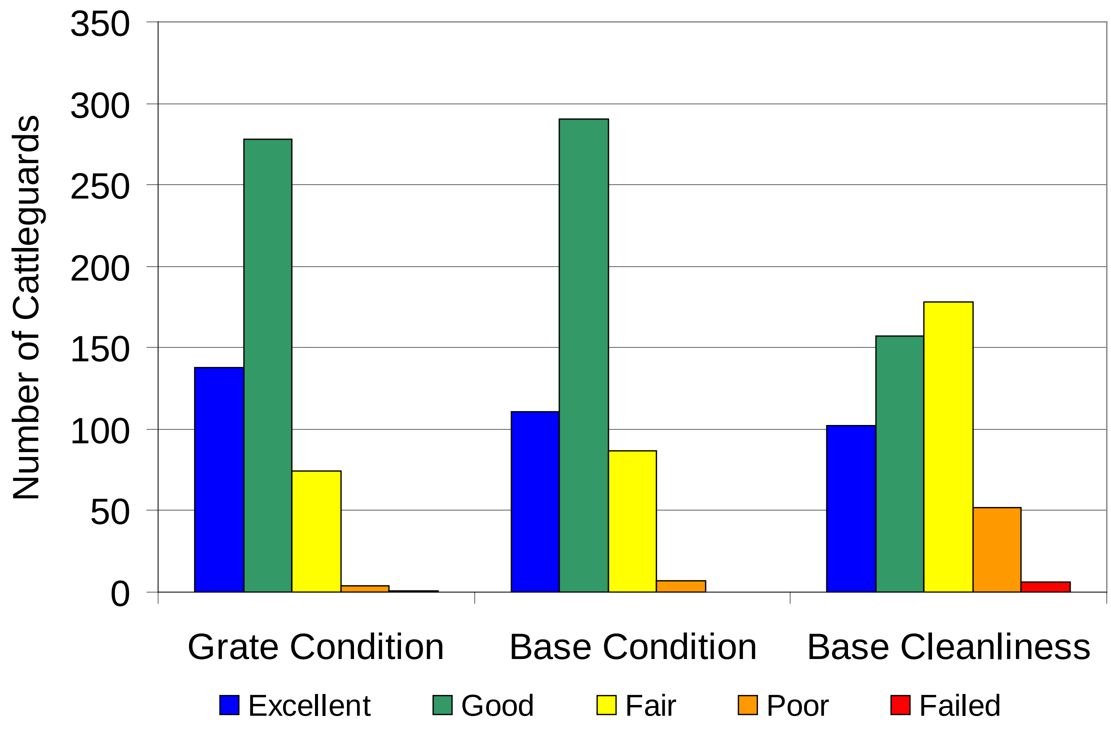

Figure 4.19 Carbon County mainline cattleguard conditions and base cleanliness.

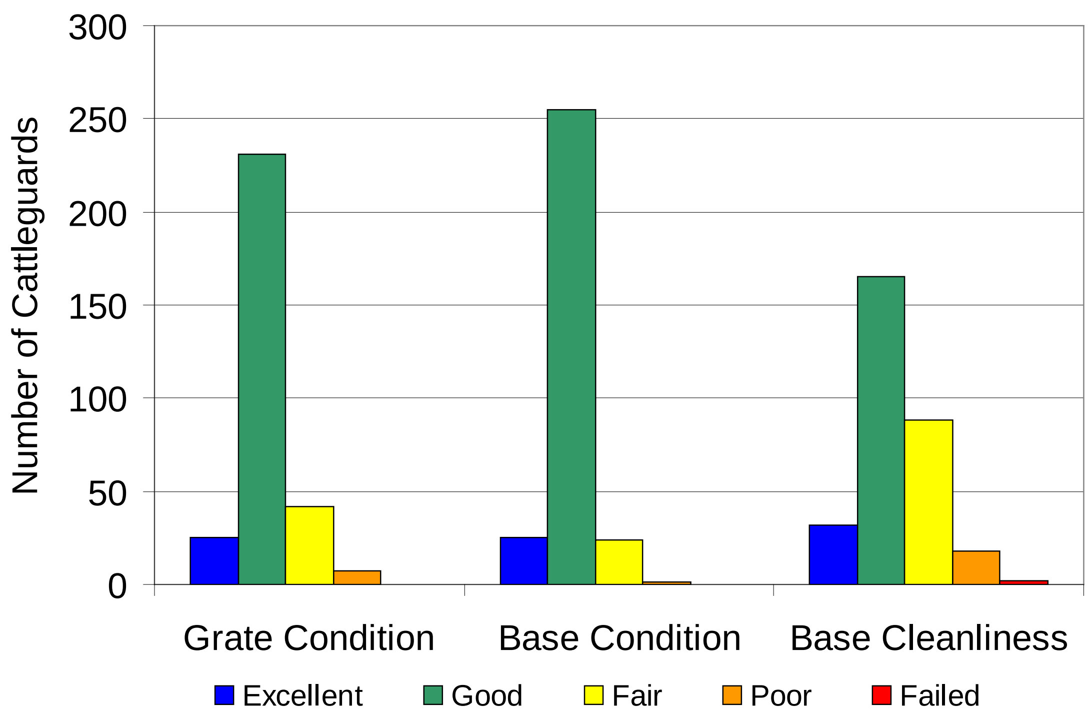

Figure 4.20 Johnson County mainline cattleguard conditions and base cleanliness.

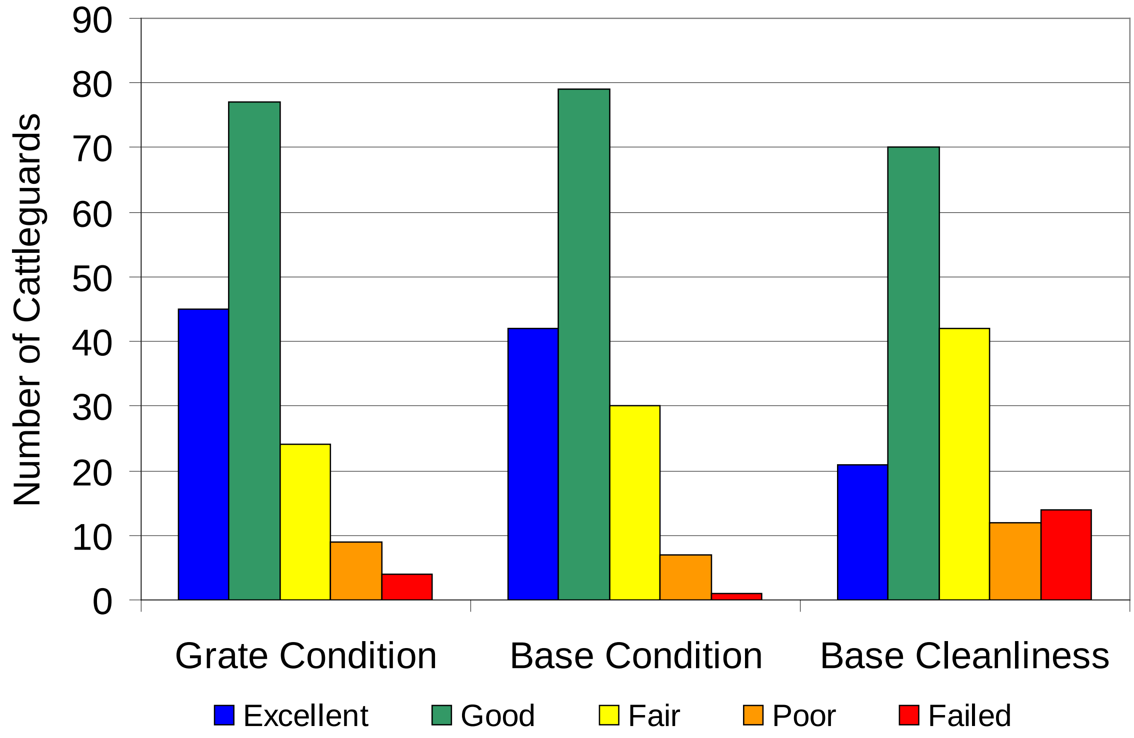

Figure 4.21 Sheridan County mainline cattleguard conditions and base cleanliness.

4.6.2 Recommended Cattleguard Improvements

Based on the condition and cleanliness of the mainline cattleguards and on the costs in Table 3.6, improvements to each county's cattleguards are recommended. Those with poor or failed grate condition, base condition, or base cleanliness are recommended for replacement or cleaning. Table 4.15 shows the recommended improvements for each county.

Table 4.15 Mainline cattleguard recommended replacements and cleaning

	Grate Replacement		Base Replacement		Clean Base		
	Number	Cost	Number	Cost	Number	Cost	TOTAL
Carbon	5	$7,500	7	$35,000	58	$29,000	$71,500
Johnson	7	$10,500	1	$5,000	20	$10,000	$25,500
Sheridan	13	$19,500	8	$40,000	26	$13,000	$72,500

4.6.3 Annual Cattleguard Cleaning and Replacement Costs

Based on the number of cattleguards in each county, the costs from Table 3.6, and the cleaning and replacement frequencies in Table 3.7, estimates of the annual cattleguard replacement and maintenance costs are made as shown in Table 4.16.

Table 4.16 Annual mainline cattleguard cleaning and replacement costs

	Replacement Costs	Cleaning Costs	TOTAL
Carbon	$128,700	$24,750	$153,450
Johnson	$79,300	$15,250	$94,550
Sheridan	$41,340	$7,950	$49,290

5. SUMMARY

5.1 System Replacement Costs

The total reconstruction costs for each county – the total value of the counties' road networks if they had to be rebuilt from scratch – are estimated in Table 5.1 as described in Section 4.1.1. It should be kept in mind that these values assume that the roads are built to current standards. Many roads are not up to current standards so the actual value of the road networks is less than the values in Table 5.1. Still, this table gives an indicator of the magnitude of the value of each county's road network. Also, the value of bridges on the county systems is not included in these estimates.

Table 5.1 Road system replacement costs

Carbon	$811,043,628
Johnson	$535,015,608
Sheridan	$450,363,823

5.2 Gravel Roads Summary

The cost of maintaining gravel and dirt roads on an annual basis is estimated based on the functional class of the road as shown in Volume III, Appendix A.6, Table A.6b. Though these maintenance funds, shown in Table 5.2, would not be spent every year on every section, they are needed on an annual average basis to prevent the roads from deteriorating to the point where they will require more expensive repairs in the future.

Table 5.2 Annual gravel roads costs per mile by functional class

	Resource	Local	Minor Collector	Major Collector
Maintenance	$282	$2,856	$6,127	$9,346
Construction	$0	$1,750	$3,855	$6,590
TOTAL	$282	$4,606	$9,982	$15,936

For a variety of reasons, such as sections that demand excessive maintenance or sections with dangerous curves and intersections, additional expenditures are recommended to upgrade the counties' gravel roads on an annual basis for a number of years to come. No such upgrades are recommended for resource roads since they carry very low traffic volumes and available funds are better spent on roads with more traffic. These expenditures would not be spent every year, but are system–wide averages over a number of years. These estimated construction costs are shown in Table 5.2.

Each county's gravel and dirt road mileages are presented in Table 5.3. Also in this table are the estimated annual maintenance costs. These costs do not consider the current road conditions, but only the mileage in each functional cost and the annual costs per mile as shown in Table 5.2. Similarly, the estimated annual construction costs are also shown in Table 5.3. These costs are based on estimates of the average annual construction costs from Table 5.2. Finally, Table 5.3 contains the cost of recommended improvements based on the road systems' current conditions.

Table 5.3 County gravel roads mileage and costs summary

	Carbon	Johnson	Sheridan
Gravel and Dirt Mileage	880	458	487
Annual Maintenance Cost	$3,603,851	$2,164,256	$2,069,765
Annual Construction Cost	$2,294,915	$1,371,691	$1,298,836
Recommended Improvement Costs	$1,913,675	$1,378,118	$3,485,914

5.3 Asphalt Roads Summary

The cost of maintaining asphalt roads on an annual basis is estimated based on the functional class of the road. These estimated maintenance costs per mile are shown in Table 5.4. Though these maintenance funds would not be spent every year on every section, they are needed on an annual average basis to prevent the roads from deteriorating to the point where they will require much more expensive repairs in the future.

Table 5.4 Annual asphalt roads costs per mile by functional class

	Local	Minor Collector	Major Collector
Maintenance	$2,651	$3,890	$4,913
Construction	$2,700	$6,025	$8,800
TOTAL	$5,351	$9,915	$13,713

For a variety of reasons, such as sections that demand excessive maintenance or sections with dangerous curves and intersections, construction expenditures shown in Table 5.4 are recommended to upgrade the counties' gravel roads on an annual basis for a number of years to come. These expenditures would not be spent every year, but are system–wide averages over a number of years.

Table 5.5 contains the asphalt roads mileages for each county. This table also shows estimated annual maintenance costs and estimated annual construction costs. The construction costs are associated with roads with excessive maintenance costs or with those that need safety or other geometric improvements. It is estimated that it will take from five to 15 years of these expenditures to address the counties' most pressing reconstruction needs. Finally, the recommended improvement costs are shown based on the current road surface conditions. The most striking figure in this table is the $44 million for improvements on Johnson County's asphalt roads. A number of asphalt roads in Johnson County are in need of significant work to keep them from deteriorating to the point where maintaining them is prohibitively expensive, as described in Section 4.3.1.

Table 5.5 County asphalt roads mileage and costs summary

	Carbon	Johnson	Sheridan
Asphalt Roads Mileages	74	105	32
Annual Maintenance Cost	$335,260	$456,022	$129,587
Annual Construction Cost	$575,343	$763,138	$204,748
Recommended Improvement Costs	$983,945	$44,712,290	$691,240

5.4 Conversion of Gravel Roads to Asphalt Roads

"The public wants as close a facsimile as possible to the higher type of pavement, bituminous concrete or bituminous macadam. Our hearts go out to a conscientious superintendent trying, under these conditions, to answer the cry of a tax–burdened public for the more modern bituminous surfacing." *(Wethearsby, 1961)*

The question of when to convert a gravel road to an asphalt road, or vice versa, is not addressed by this study. While there are other studies addressing this issue *(Jahren et al, 2005)*, they do not directly consider the unique aspects of Wyoming's boom–bust economy. Some roads, such as Lower Prairie Dog Road in Sheridan County, Irigaray Road in Johnson County, and Wamsutter Road in Carbon County, should be turned into hot mix asphalt roads, except for one thing: we know that usage on these roads will not remain at their current levels, making the major investment of reconstructing these roads with hot mix asphalt less cost effective. Once wells have been drilled in the areas served by these roads, their usage, particularly by heavy trucks, will fall off dramatically. Then the counties will be stuck with an asphalt road that demands long–term maintenance, not to mention the initial waste of resources involved in over–building the roads.

The estimated average annual costs (see Tables 5.2 and 5.4) for local roads are lower for gravel roads – $4,606 for gravel and $5,351 for asphalt – while asphalt is cheaper for major collector roads – $15,935 for gravel and $13,713 for asphalt. Annual costs for minor collector roads are virtually the same – $9,982 for gravel and $9,915 for asphalt. This agrees with other estimates of when to convert a gravel road to asphalt which are in the neighborhood of 100 to 250 vehicles per day – the system presented in this study estimates traffic on minor collector roads at 150 vehicles per day (see Table 3.3). There are many other factors that go into deciding of whether a road's surface should be paved; dust concerns, particularly in residential areas, are one factor that weighs against returning an asphalt road to gravel. Keeping in mind that asset management is an analytical tool, not a final decision maker, one would not be too far off the mark to consider major collector gravel roads as candidates for paving, while local asphalt roads might be turned into gravel roads; minor collector roads should be addressed on a case–by–case basis.

When making assessments as to whether a road should be changed from gravel to asphalt, a life cycle cost analysis should be performed, considering the probable reduction in heavy truck traffic that may take place when drilling served by the road ends, as well as costs to the road's users and environmental effects, primarily dust.

5.5 Signs

The recommended sign expenditures in Section 4.4 are summarized in Table 5.6. This table contains long–term recommendations and should be used only as guidelines for future expenditures on signs. Ideally, all these improvements would be made immediately, but financial constraints are likely to make this approach impractical. However, plans should be made to address both the quality and quantity of signs on the counties' road networks by implementing these improvements over time. As additional signs are installed, the annual costs of maintaining the counties' signs will increase correspondingly. At a bare minimum, the annual maintenance costs should be funded simply to maintain the existing signs.

Table 5.6 Sign costs summary

	Annual Cost of Maintaining Existing Signs	Annual Cost of Maintaining Additional Signs	Cost of Recommended Improvements	Cost of Recommended Additional Signs	TOTALS
Carbon	$75,735	$21,010	$273,167	$441,201	$811,113
Johnson	$21,787	$19,643	$84,276	$412,512	$538,218
Sheridan	$62,238	$1,850	$213,285	$38,842	$316,215

These estimates are made without the benefit of knowing the retroreflectivity – nighttime visibility – of the signs. As the Federal Highway Administration (FHWA) contemplates imposing retroreflectivity standards on county signs, counties must be aware that many signs may need to be replaced in the near future. While an attempt has been made to guess at the retroreflectivity by rating sign sheeting in otherwise good condition as either excellent or faded, it is impossible to accurately assess most signs' retroreflectivity unless they are observed at night or tested with a retroreflectometer. Assuming the FHWA actually imposes retroreflectivity standards, each county will need to assess its signs' retroreflectivity and budget accordingly to address deficiencies.

5.6 Culverts

The total costs estimated for culverts for each county are shown in Table 5.7.

The annual costs are estimates of the cost of cleaning, maintaining, and replacing the existing culverts in each county. They do not include the cost of adding additional culverts, such as on reconstructed sections of road or where culverts have proven to be undersized during flooding events.

The recommended improvements costs cover those culverts that are damaged or clogged. They do not address the issues of improperly placed culverts, the installation of new culverts, or extending culverts that aren't long enough.

Table 5.7 Culvert costs summary

	Annual Costs	Improvement Costs
Carbon	$199,493	$407,950
Johnson	$181,104	$580,635
Sheridan	$238,038	$735,720

5.7 Cattleguards

The costs of maintaining and improving each county's cattleguards are shown in Table 5.8.

Table 5.8 Cattleguard costs summary

	Annual Costs	*Improvement Costs*
Carbon	$153,450	$71,500
Johnson	$94,550	$25,500
Sheridan	$49,290	$72,500

5.8 Drilling Impacts

5.8.1 Drilling Impacts on Gravel Roads

The impact of drilling activities is perhaps best seen when one looks at the gravel drilling roads recommended for improvements. The roads listed in Table 5.9 are those gravel roads that have been identified as those that receive predominantly drilling–related traffic. This table shows the cost of recommended improvements on these roads and the percentage of the total gravel roads improvements recommended for each county on roads receiving a lot of drilling traffic.

For the three counties together, 15% of the total gravel roads mileage is on roads categorized as drilling roads, but about half of the total recommended improvements are on the drilling roads. This indicates that the roads with a lot of drilling traffic have been damaged substantially more than those roads without drilling traffic, thus they are in need of more improvements. Figure 5.1 plots the percentages of miles and recommended improvement costs for each county and for the three counties together. In all cases, this shows that the proportion of recommended improvements on drilling roads is much higher than would be expected based on the percentage of the total mileage for drilling roads when compared to non–drilling roads.

Figure 5.1 demonstrates that while drilling roads represent a relatively small percentage of each county's road network, they represent a much higher percentage of the recommended improvements. This indicates that the drilling roads are being damaged faster than the counties are able to maintain them, and that they are being damaged significantly faster than the other roads on the counties’ road networks.

Table 5.9 Drilling roads with their recommended improvements as a percentage of total recommended improvements and each county system's mileages

County	Road Name	Road Number	Functional Class	Total Miles	Miles Improved	Improvement Costs
Carbon	Wamsutter	701	Major Collector	18.8	8.0	$545,281
	Twenty Mile/JO	605S	Minor Collector	2.2	2.0	$347,946
	Twenty Mile/JO	605N	Major Collector	23.1	4.2	$209,491
	Poison Butte/Government	700	Minor Collector	17.9	3.0	$103,251
	Ferris Crossing	340	Major Collector	1.2	1.0	$86,528
	Paintbrush	730	Local	6.0	2.0	$23,444
	Oil Springs	294	Local	4.9	0.0	$0
	Medicine Bow - McFadden	1	Minor Collector	19.7	0.0	$0
	Ferris	100	Resource	14.4	0.0	$0
	Cherry Grove	501	Local	7.5	0.0	$0
			Drilling Subtotals	116	20.1	$1,315,941
			County Totals	880	48.9	$1,913,675
			Drilling Percentage	13%	41%	69%
Johnson	Schoonover	204B	Major Collector	24.2	24.2	$193,333
	190	190	Local	4.0	3.0	$160,963
	Upper Powder River	195	Minor Collector	27.0	9.0	$158,974
	Dead Horse	259	Major Collector	6.1	6.1	$131,791
	TTT	51	Minor Collector	14.0	5.5	$67,811
	Tipperary	54	Minor Collector	21.8	4.0	$60,118
			Drilling Subtotals	97	51.7	$772,989
			County Totals	458	74.3	$1,378,118
			Drilling Percentage	21%	70%	56%
Sheridan	Lower Prairie Dog	1211	Major Collector	14.8	14.8	$804,439
	Upper Powder River	273	Minor Collector	7.1	5.1	$302,576
	Wild Horse	38	Minor Collector	6.5	3.9	$220,038
	Coutant Creek	114	Minor Collector	3.3	2.3	$87,974
	Beatty Gulch	1231	Minor Collector	12.3	3.0	$82,936
	Arvada-Gillette	40	Local	10.0	0.0	$0
			Drilling Subtotals	54	29.1	$1,497,963
			County Totals	487	80.7	$3,485,914
			Drilling Percentage	11%	36%	43%
All Three Counties			*Drilling Subtotals*	267	101.0	$3,586,893
			County Totals	1825	203.8	$6,777,707
			Drilling Percentage	**15%**	**50%**	**53%**

Looking at the increased rates of improvement recommendations on drilling roads in more detail, one should consider the miles of drilling roads in each functional class. Table 5.10 shows the miles of drilling roads in each county and functional class. It should be kept in mind that the determination of whether a road is classified as a drilling road or not is based on best estimates, not on actual traffic studies. Also, roads carry varying fractions of drilling traffic. Roads do not carry 0% or 100% drilling traffic, rather, those roads that are categorized as drilling roads are believed to carry predominantly drilling traffic.

Table 5.10 shows that, for the three counties together, 15% of the total miles of county roads are categorized as drilling roads, though for major collector roads, over half the mileage is categorized as drilling roads.

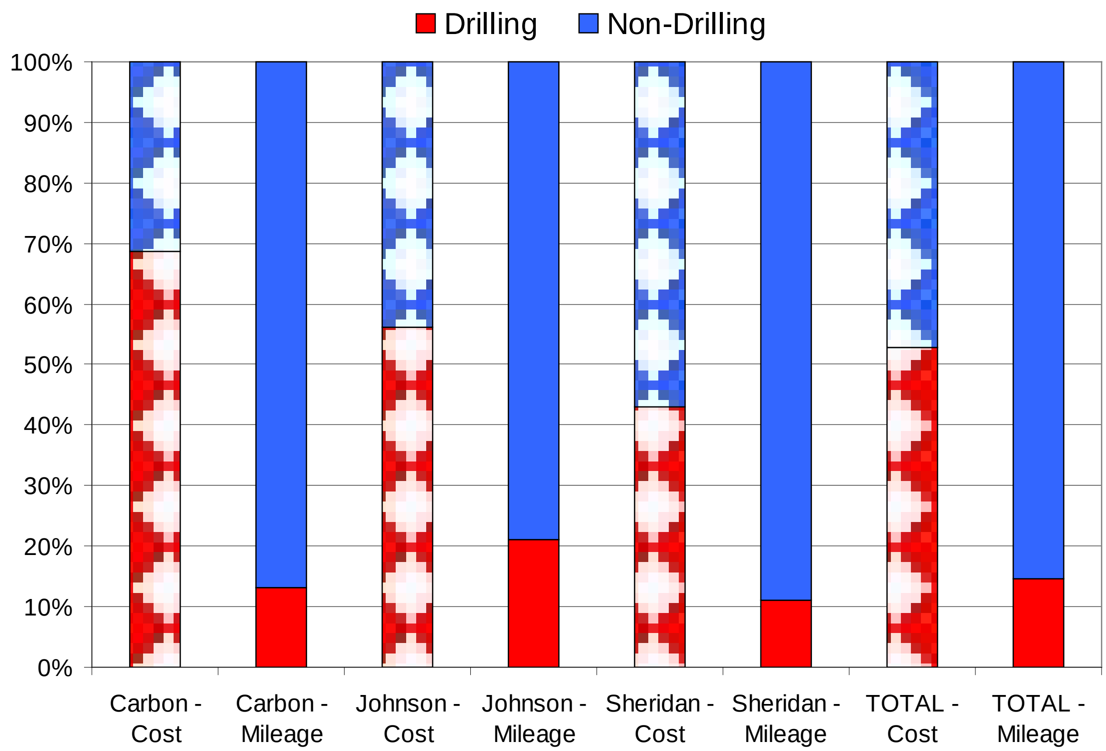

Figure 5.1 Recommended improvement costs and mileages for drilling *vs* non–drilling gravel roads.

Table 5.10 Mileages of drilling roads by functional classification

County		Mileages Resource	Local	Minor Collector	Major Collector	TOTAL
Carbon	*Drilling*	14	18	40	43	116
	Total	209	281	281	109	880
	Drilling Percentage	7%	7%	14%	39%	13%
Johnson	*Drilling*	0	4	63	30	97
	Total	36	166	222	34	458
	Drilling Percentage	0%	2%	28%	89%	21%
Sheridan	*Drilling*	0	10	29	15	54
	Total	71	176	215	25	487
	Drilling Percentage	0%	6%	14%	61%	11%
All Three Counties	*Drilling*	14	32	132	88	267
	Total	315	624	718	168	1825
	Drilling Percentage	**5%**	**5%**	**18%**	**53%**	**15%**

The cost of recommended improvements on gravel roads by functional class for drilling roads and for all roads is shown in Table 5.11.

Table 5.11 Recommended improvement costs on drilling roads and on all roads

County		Recommended Improvement Costs: Resource	Local	Minor Collector	Major Collector	TOTAL
Carbon	*Drilling*	$0	$23,444	$451,197	$841,300	$1,315,941
	Total	$108,661	$163,974	$681,876	$959,163	$1,913,675
	Drilling Percentage	0%	14%	66%	88%	69%
Johnson	*Drilling*	$0	$160,963	$286,903	$325,124	$772,989
	Total	$0	$246,607	$518,594	$612,917	$1,378,118
	Drilling Percentage	--	65%	55%	53%	56%
Sheridan	*Drilling*	$0	$0	$693,524	$804,439	$1,497,963
	Total	$108,165	$468,961	$1,545,278	$1,363,510	$3,485,914
	Drilling Percentage	0%	0%	45%	59%	43%
All Three Counties	*Drilling*	$0	$184,406	$1,431,624	$1,970,863	$3,586,893
	Total	$216,826	$879,542	$2,745,749	$2,935,590	$6,777,707
	Drilling Percentage	**0%**	**21%**	**52%**	**67%**	**53%**

Table 5.12 compares the percentage of miles on drilling roads with the percentage of recommended improvement costs on these same drilling roads.

Table 5.12 Percentage of miles and recommended improvement costs on drilling roads

		Resource	Local	Minor Collector	Major Collector	TOTAL
Carbon	Cost %*	0%	14%	66%	88%	69%
	Miles %**	7%	7%	14%	39%	13%
Johnson	Cost %*	--	65%	55%	53%	56%
	Miles %**	0%	2%	28%	89%	21%
Sheridan	Cost %*	0%	0%	45%	59%	43%
	Miles %**	0%	6%	14%	61%	11%
TOTAL	Cost %*	0%	21%	52%	67%	**53%**
	Miles %**	5%	5%	18%	53%	**15%**

*Percentage of Recommended Improvement Costs on drilling roads

**Percentage of Functional Class mileage on drilling roads

If drilling activities are negatively impacting county gravel roads, one would expect drilling roads to have a higher rate of recommended improvements than the counties' systems as a whole. Overall, this expectation is met, except for the very low volume resource roads; of the $6.8 million of recommended improvements to gravel roads, only $0.2 million are on resource roads, so one should not attach too much significance to this discrepancy. The other discrepancies to the expectation that drilling roads have been damaged significantly more than other roads are on the major collector roads in Johnson and Sheridan counties.

In Sheridan County, in addition to the expected recommended improvements on Lower Prairie Dog Road, a drilling road with about $800,000 of recommended improvements, there are significant improvements recommended to Box Cross Road, which has many residences, and to the east end of Red Grade Road, which has both residential and recreational uses. Based strictly on the information made available by this study, it would be difficult to argue that drilling has significantly impacted the relative costs on drilling and non–drilling roads. However, based on various observations and conversations, it is apparent that maintenance expenditures on the drilling road, Lower Prairie Dog Road, are dramatically higher than those on either Red Grade Road or Box Cross Road, so the true costs of the drilling road are much higher than they appear to be from the information presented here.

On Johnson County's gravel major collector roads, the west end of TW Road, which is not categorized as a drilling road, has about $300,000 of recommended improvements, while Schoonover and Dead Horse roads, which are categorized as drilling roads, have about $325,000 of recommended improvements. TW Road serves the local landfill, and it also receives a significant amount of both drilling and residential traffic; these factors combine to cause significant damage to TW Road, thus equalizing the damage between drilling and non–drilling roads.

In spite of the discrepancies described in the previous three paragraphs, the overall picture is clear: Drilling traffic significantly increases the need for improvements on the counties' gravel roads. Drilling roads account for 15% of the total mileage on the three counties' gravel roads and they account for 53% of the recommended improvements on these same roads.

5.8.2 Drilling Impacts on Asphalt Roads

The impact of drilling traffic on the three counties' asphalt roads cannot be adequately assessed. There aren't enough asphalt roads to provide a good basis for drawing such conclusions. Also, asphalt roads are not at all evenly distributed throughout the counties, as are gravel roads. In Sheridan County, most of the asphalt roads are near the City of Sheridan. In Carbon County, the Seminoe and Sage Creek roads comprise a large portion of the asphalt roads – neither of these roads has substantial drilling traffic. In Johnson County, the vast majority of the recommended improvements to asphalt roads are on Trabing and Irigaray roads that receive some drilling traffic, but drilling traffic is not the predominant type of traffic, at least at the time of this study. Without better data on the percentage of drilling traffic on the three counties' asphalt roads, it is not possible to assess the damage to asphalt roads by drilling traffic.

5.9 Overall System Recommended Improvements

Estimates have been made of the cost of each county's total recommended improvements as shown in Table 5.13. Figure 5.2 shows the recommended improvement costs for asphalt and gravel roads in Johnson County. The generation of these costs is described in Sections 4.2.1 (gravel), 4.3.1 (asphalt), 4.5.3 (culverts), 5.5 (signs), and 4.6.2 (cattleguards). These values do not include improvements needed for geometric or safety issues, such as blind curves or dangerous intersections. Also, costs related to replacing and repairing bridges are not included.

Table 5.13 County systems' estimated total recommended improvement costs

County	Gravel	Asphalt	Culverts	Signs	Cattle guards	TOTALS
Carbon	$1,913,675	$983,945	$407,950	$811,113	$71,500	$4,188,183
Johnson	$1,378,118	$44,712,290	$580,635	$538,218	$25,500	$47,234,761
Sheridan	$3,485,914	$691,240	$735,720	$316,215	$72,500	$5,301,590

The high value shown in Table 5.13 for Johnson County is due to several asphalt roads that are structurally inadequate and that should be reconstructed as explained in Section 4.3.1.

5.10 Annual Construction and Routine Maintenance Costs

The cost of maintaining each county's road surfaces, culverts, signs, and cattleguards on an annual basis have been estimated as described in Sections 4.2.2 (gravel), 4.3.2 (asphalt), 4.54 (culverts), 5.5 (signs), and 4.6.3 (cattleguards). These estimates are shown in Table 5.14.

Table 5.14 County road systems' estimated annual construction and routine maintenance costs

County	Gravel	Asphalt	Culverts	Signs	Cattle guards	TOTALS
Carbon	$3,603,851	$910,602	$199,493	$96,745	$153,450	$4,964,141
Johnson	$2,164,256	$1,219,161	$181,104	$41,430	$94,550	$3,700,501
Sheridan	$2,069,765	$334,335	$238,038	$64,088	$49,290	$2,755,516

The estimated annual construction costs include upgrades to improve safety and the roads' geometries. Though there are not sufficient data to accurately estimate the amount of geometric upgrades needed, funding at these levels for about five to 15 years should get the counties' roads in significantly improved condition. However, costs related to maintaining and upgrading bridges are not addressed in this estimate.

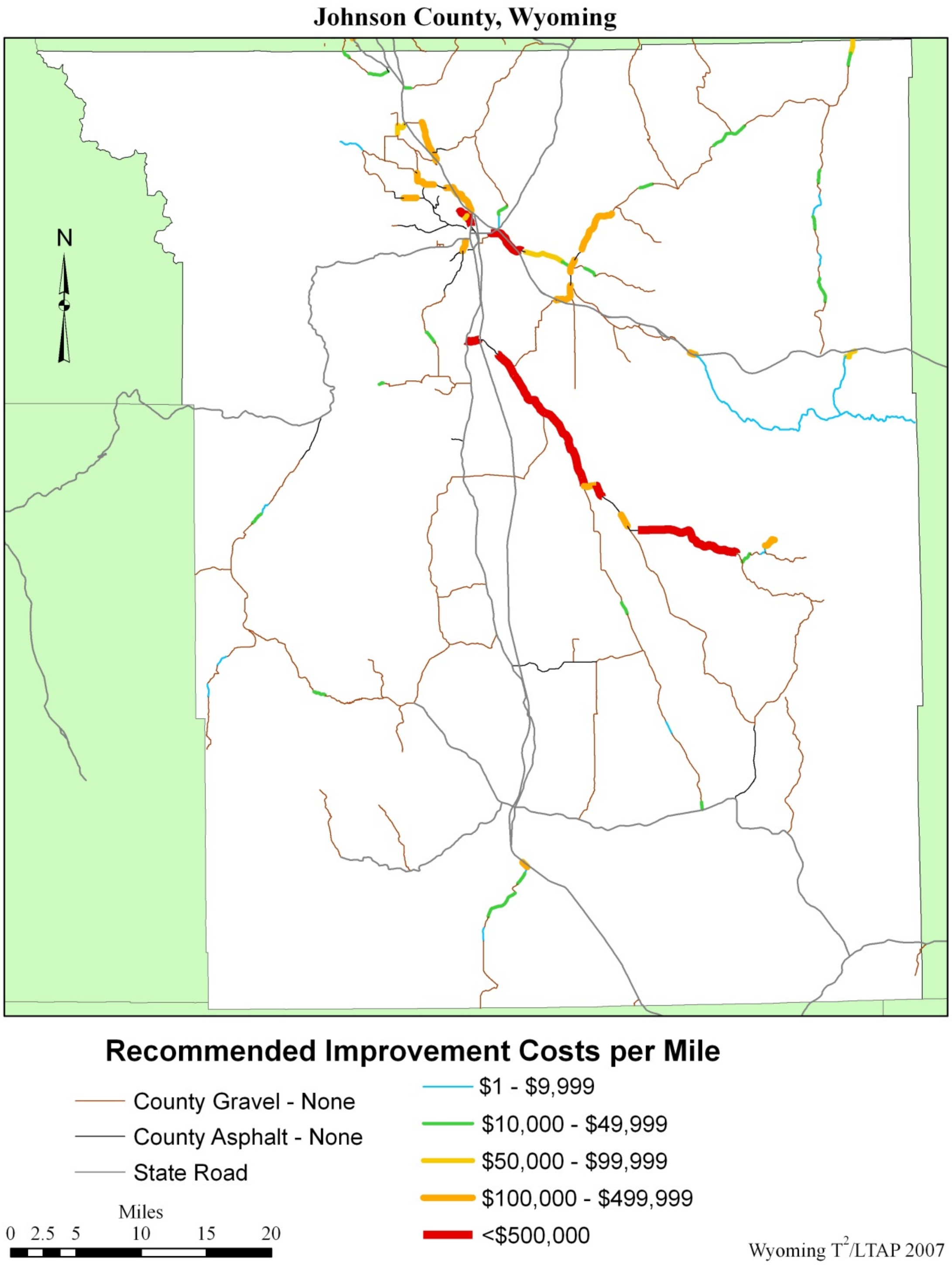

Figure 5.2 Johnson County recommended improvement costs per mile.

6. STATE OF THE PRACTICE IN WYOMING COUNTIES

During the summer of 2007, the T^2/LTAP Center conducted a phone survey with most of the counties in Wyoming in an attempt to assess the asset management practices currently used in Wyoming's counties. All counties are required to inventory and estimate the value of their assets as part of the federal GASB 34 requirements. The following discussion covers both those practices being followed to satisfy the GASB 34 legislation and those practices that go beyond GASB 34 to provide counties with additional benefits.

Sheridan, Johnson, and Carbon counties have the asset management program described in this report.

6.1 Satisfying GASB 34 Requirements

Several approaches may be taken to inventory and value county roads. The simplest is to inventory the county’s assets, such as roads, culverts, signs, and bridges. Then one can assume typical unit costs for the various assets. Multiplying the typical unit costs by the length of roads or culverts or by the number of signs or cattleguards gives a value of the counties' assets. A more complex approach involves taking the initial construction costs and depreciating them out over time to come up with a present worth of the various assets.

It is difficult to assess the current value of roads. If one considers total replacement costs, one gets very high values, such as those on the order of half a billion dollars per county as shown in Table 5.1a. However, the current value is certainly lower than these values which assume all roads are built to current standards. Certainly, many county roads are not built to current standards appropriate for the amount and type of traffic they receive. Thus, their current value is less than their replacement cost. Depreciation of roads can be difficult to assess. Even bridges are far simpler: the structural elements of a bridge deteriorate with time, and eventually they must be replaced, regardless of their functional adequacy. This is not necessarily true of roads, particularly gravel roads. A gravel road that receives little or no maintenance, does not have additional gravel placed in a timely manner, and does not receive adequate drainage maintenance might reasonably be depreciated over as little as 10 years. However, if the same road is well maintained, is reshaped regularly, has additional gravel applied as necessary, and the drainage is well maintained, the road might easily last 100 years without any major work. The reality on the ground is somewhere between these two extremes. But when using the depreciation method to assign a value to a county's road network, widely varied estimates may be achieved, depending on the depreciation period. While there are similar issues for other assets, such as bridges, culverts, and signs, far and away the greatest uncertainty in any estimate of the value of a county's road and bridge network will be in the value of the roads themselves.

6.2 Software, GIS, and GPS: Current Capacities

Most counties in Wyoming have hired or are considering hiring an individual whose primary function will be to administer and develop geographic information systems (GIS). Often these positions have been created to help the county assessor's office track land ownership. Given the spatial nature of road and bridge networks, GIS is an obvious planning and management tool for any road and bridge department. Once a GIS system is set up and in place, the day–to–day running of these systems may not always be a truly full time occupation for a skilled GIS person. This provides an opening for road and bridge departments – a trained person may already be available on staff and have the time to help the road and bridge department implement a GIS–

based tool to improve their planning and management capabilities. Even for counties that do not currently have such an individual on their staff, the time savings realized by such a person would, for most counties, justify the expense of a GIS person. And for those smaller counties that might not realize as a great savings from a dedicated GIS employee, there are still benefits that might be realized from working with the private sector or with other similar counties to provide the advantages of a GIS–based management tool.

6.3 Cost Tracking

Tracking costs is an issue closely associated with asset management. Costs are a critical input to an asset management system. Cost tracking is the process of entering all expenses and, ideally, of determining the precise segment of road on which funds are spent.

Most counties have some way of tracking their expenses. Some counties use commercially available software to perform this function. Others have developed their own spreadsheets to track expenses. Generally, these expenses are, at best, attributable to a road, though usually there is no more specific information as to which part of a particular road the work has been performed.

6.4 Data Collection

There is extensive variability both in the types of data collected and the methods of collecting data in the various counties.

In some counties, data are collected with handheld GPS data collection units, while in others, GPS locations are entered by hand from a personal GPS unit. In still others, only roads or approximate mileages are available.

Sometimes data are collected by road and bridge crews, sometimes by GIS crews, and sometimes by third parties.

Many counties have their own traffic counters to provide data on traffic types and volumes.

6.5 Uniformity and Consistency of Data Among Wyoming Counties

Counties in the state have widely varying capability levels. This assessment of asset management practices by Wyoming counties clearly indicates that there is no uniform and consistent procedure to evaluate current conditions and justify future needs on a statewide basis. It would be beneficial for the counties to establish uniform guidelines to identify their needs based on a systematic procedure. The counties can then approach state legislators with their combined, documented needs.

7. IMPLEMENTATION RECOMMENDATIONS

As a pilot project, one of the primary objectives of this study is to develop the expertise necessary to implement asset management programs on a statewide basis. As the single most valuable asset held by most Wyoming counties, roads must be managed effectively and efficiently. Applying the knowledge developed during this project should be combined with an honest assessment of county governments' needs in their efforts to provide a good county road system. This chapter provides recommendations on how to implement future asset management systems for Wyoming counties.

It is in the best interests of Wyoming's counties to have a standardized method for tracking road and bridge assets. This will provide consistent figures for the State legislature and for WYDOT when assessing counties' road and bridge needs. Without any standardized procedures, it is very difficult to compare the needs of various counties. Without any standardized procedures, counties may be tempted to overestimate the severity of their problems in an attempt to secure funding, or they may be tempted to minimize their problems because of political pressures. Without a consistent means of gathering data and evaluating road networks, it will not be possible to realistically assess the condition of county roads on a statewide basis. Without a realistic assessment of current conditions, it is very difficult to assess the counties' needs on a statewide basis.

Timely updates are crucial to the success of any asset management system. Old data are of little value. Without a commitment to keep an asset management system current and a procedure in place for ongoing data collection, a system will soon become obsolete. A commitment to keeping a database current is essential to the successful implementation of any asset management system.

The goal of further implementation efforts is to establish effective asset management systems for other counties throughout the state. Some counties have fairly well developed asset management systems already in place, while others do not yet have the in–house expertise, particularly GIS–trained personnel, to undertake such an effort at this time. However, there are a number of counties within the state that do not have a well–developed system, but who have the necessary tools to begin developing an effective asset management system. These counties, with assistance from the T^2/LTAP Center, are ready to implement an asset management system. Sections 7.2 and 7.3 describe some of the implementation processes and issues they will face, along with the role the T^2/LTAP Center might play as these systems are put into place.

7.1 Implementation Processes

The Wyoming T^2/LTAP Center is prepared to assist the counties of Wyoming with their own asset management systems. Details on some of the implementation processes and issues are summarized in Appendix A.16. Standardized financial and engineering assessments can be achieved with training and analysis provided by the Center.

Implementation should take place with the advice and assistance of county personnel with relevant expertise. Road and bridge personnel should be involved, as should GIS professionals already working with the county. The steps below are possible steps a county might take, with assistance from the T^2/LTAP Center, for such implementations:

- County and T^2/LTAP develop a general plan, budget, and proposal
- Secure funding from WYDOT and others

- Develop specific software, hardware, and training needs
- Acquire and modify existing software and hardware
- Hire and train personnel to perform initial data collection activities
- Train personnel to perform field data updates

Once these steps have been taken and data have been collected, the Center could analyze a county's data on an annual basis, generating reports with standardized methods and formats, using data collected in a timely, standardized manner, thereby providing consistent financial and engineering reports from across the state.

7.2 Implementation Issues

7.2.1 Training

The Wyoming T^2/LTAP Center has the capacity to provide standardized training in data collection and analysis. The primary goal of this training would be to have all counties rate features in a consistent manner. Ratings for roads – asphalt, sealcoat, earth, gravel, and concrete roads – should be based on the Wisconsin Transportation Information Center's PASER (pavement surface evaluation and rating) manuals, and these manuals should be provided to the road evaluators to maximize the consistency of ratings from county to county. Training materials already developed by the Center (see Appendix A.17) would be used to provide consistent evaluation training across the state.

7.2.2 Software

Training should be preceded by development and installation of software for performing data entry on the modules in which training is to be performed. Though data could be collected manually then entered into a database in the office, this unnecessarily adds an extra step. For a module rarely used, such as concrete roads, this might be practical, but the additional labor entailed by entering data twice, once by hand on paper and once transferring data from hard copies to the electronic database is a waste of effort.

The T^2/LTAP Center could provide counties with the data collection software developed as part of this project. For this to be practical, a number of fields currently entered by hand, such as road names and sign MUTCD codes, should be selected from a drop–down list for each county. Analysis time for this project has been significantly hampered by having slightly different formats for a number of entries. Providing drop–down lists, rather than text entry fields, would significantly reduce these problems. It might be possible for GIS personnel in counties around the state to share improvements to the software in an open source code environment, possibly expanding to other states in the future. Similar sharing could aid in map and report generation as well.

7.2.3 Analysis of County Surface Condition Data

Analysis training, at least for GIS–based applications, could consist of training in the ESRI ArcGIS products, which were used by T^2/LTAP for the asset management program described in this report. The mechanics of generating maps and reports tailored to a county's current needs would be the primary focus of this training. Such training would consist of generating maps in ArcMap and transferring data to Excel for report generation, unless software was developed to automatically generate reports. Additional training in report generation in Excel might also be provided.

If counties generated data following the models presented in this report, the analytical software developed as part of this project could be used to analyze condition data from the counties. For this to be practical, counties would need to submit data in formats consistent with those used by T^2/LTAP in this project.

Among the software developed at T^2/LTAP and at several counties around the state, a significant amount of software has already been developed. This software would be useful to other counties with less advanced asset management systems in place. Sharing code between T2/LTAP and county GIS personnel might make the process of developing asset management systems much easier throughout the state. Communication and sharing among those managing these systems should make the entire process easier and more efficient for all.

7.2.4 Integration of Cost Tracking and Asset Management

Most counties already have some way of tracking their costs. Since cost data are a critical input into the asset management system, taking cost data generated by the counties and inserting them into the analytical software used to perform projections and analyses of county data would help to provide more accurate results from the asset management program. The cost data found elsewhere in this report could easily be updated with data from an individual county so the analyses performed for that county would more accurately reflect their actual costs.

If cost data can be tracked by individual road segments, the performance and maintenance demands of specific segments can be compared to other roads throughout the county and the state.

7.2.5 Updating System and Cost Inputs

The numerous tables in Section 3 of this report should periodically be evaluated and updated to reflect the practices and performances observed throughout the state. Such updates should be performed on an ongoing basis as more is learned about the performance of roads throughout the state. Collecting data in a consistent manner will allow for further refinement of the models described in this report, thereby generating more accurate projections in the future.

7.2.6 Additional Areas of Analysis

The system described in this report focuses primarily on road surface conditions. Other features could also be incorporated in an asset management system. The following list contains some of the additional features that might be collected as part of an asset management system:

- Crash data
- Right–of–way and easements
- Utilities
- Snow fences
- Hydrology
- Bridge conditions
- Fences
- Roadway geometry and safety

- Approach permits
- Guardrails
- Delineators
- Maintenance requests
- School bus routes
- Postal routes

7.3 Conclusions

The Wyoming T^2/LTAP Center, with advice and cooperation from the Wyoming Department of Transportation and Sheridan, Johnson, and Carbon counties has developed an asset management system tailored to the needs of Wyoming's rural counties, with a focus on gravel roads. This system provides assessments of the county roads' current conditions and evaluates their maintenance and rehabilitation needs now and in the future.

This report contains information on the fiscal needs of Carbon, Johnson, and Sheridan counties that should be used by these counties' commissioners as they allocate funds to their road and bridge departments. When these needs cannot be met with county funding sources, other funds should be sought from, among others, the state legislature.

The Center has developed several products that may be used as other counties implement their own asset management systems. Data collection and analysis software developed for this study may be used by other counties as they develop their own systems. The training materials and analytical procedures developed during this study can be used to provide consistent assessments throughout the state.

As more counties put asset management systems in place, they should use the data collection and analysis techniques developed for this study so the needs of different counties can be compared and evaluated with the knowledge that they have been obtained using consistent methods. The Wyoming T^2/LTAP Center is prepared to provide data collection training and analysis services, thereby making realistic county–to–county comparisons so policy makers can compare maintenance and rehabilitation needs of different counties with the knowledge that the data and results have been obtained using the same procedures.

The Wyoming T^2/LTAP Center recommends that the following steps be taken as other county road and bridge departments implement asset management programs:

- Encourage county commissioners and state legislators to act on the results presented in this report.
- Regularly update the GIS–based database included on the CD that accompanies this report. This will require a commitment by the counties to routinely update their databases.
- Encourage other counties to adopt the data collection and analysis standards developed as part of this study so that consistent, statewide analytical results may be achieved.
- Modify and improve the data collection and analysis software developed as part of this study.
- Modify and improve the data collection training materials developed as part of this study.
- Provide training on data collection methods so roads and other features are rated throughout the state in a consistent manner.

- Perform analysis using uniform methods such as those presented in this report so comparable and consistent statewide results may be derived and presented to policy makers.
- Assess needs not addressed by this study on a statewide basis, particularly bridge upgrades, geometric improvements that enhance safety and serviceability, and structural improvements that enhance durability and lower maintenance costs on county roads.
- Compile statewide data on the needs of each county's road and bridge departments.

The Wyoming T^2/LTAP Center recommends that this pilot study be expanded to include other counties that are well positioned to implement or upgrade their own asset management programs.

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ASSET MANAGEMENT FOR WYOMING COUNTIES

Volume II of III

(Example of Annual Summary Report)

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Wyoming Technology Transfer Center
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August 2011

EXAMPLE ANNUAL SUMMARY REPORT

The following pages contain an example (presented to Sheridan County by the T^2/LTAP Center in the spring of 2006) showing how annual reports from an asset management program might appear. Though future reports would certainly vary from this, the overall methods of presentation would be similar to those shown in this appendix.

ASSET MANAGEMENT SYSTEM FOR SHERIDAN COUNTY

Prepared by
Wyoming T^2/LTAP Center

ACKNOWLEDGEMENT

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DISCLAIMER

The contents of this report reflect the work of the authors, who are responsible for the facts and the accuracy of the information presented. This document is disseminated under the sponsorship of the Wyoming Department of Transportation and the Wyoming Technology Transfer Center, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

Table of Contents

1. BACKGROUND

The Wyoming Technology Transfer (T^2/LTAP) Center has completed the second year of a three-year project. The main goal of this project is to develop asset management programs for Sheridan, Johnson, and Carbon Counties. These asset management programs have two objectives. The first is to evaluate the financial needs of the counties' road and bridge departments. These needs include the routine maintenance and construction costs of roads, as well as estimates of the repairs needed to bring the county road networks up to adequate standards. The second goal is to provide the county road and bridge crews with tools to allow them to operate their departments more effectively and efficiently.

The project was undertaken with support from the Wyoming Department of Transportation (WYDOT). The impetus behind the project was to assist these three counties in dealing with increasing impacts from oil and gas drilling. Although it's well known that these three counties are experiencing considerable impacts from drilling activities, there are inadequate data on the magnitude of these impacts. In assessing these counties' needs, one goal is to come up with estimates of the impacts of drilling activities on the counties' road and bridge financing needs.

1.1 Asset Management Program Methods

The asset management program, in the simplest terms, is an inventorying and rating system for county roads. The Wyoming T^2 Center hired and trained students and retirees to rate all county roads in one–mile segments. They also located and rated culverts, cattleguards, signs, and approaches. Bridges were located but not rated – WYDOT rates all bridges over 20' long. Locations of the road segments and other features are established with global positioning system (GPS) technology and stored in a geographic information system (GIS) database. The analysis was performed by the T^2 Center staff.

This report provides some preliminary results from the asset management program for Sheridan County's assets. As the program moves into its third and final year, more accurate data related to cost and traffic will become available, which should result in more precise prediction of future needs. The additional data will facilitate doing life cycle cost analysis of gravel roads. When the final report is prepared, year–to–year comparisons will be made to assess the overall condition of the county's roads. The data in this report are based on the data collected in 2005 only. It will be interesting to see how the ratings vary from year to year and from data collection team to data collection team. The findings presented in this report are based on estimated maintenance and rehabilitation costs to illustrate the magnitude of the county's road and bridge department expenses. It should also be mentioned that other major expenses – such as bridges – are not addressed in this report.

2. METHODOLOGY

In order to satisfy the objective of this study, a roadway functional classification had to be defined and established. In addition, an overall surface condition index was developed. This section describes these two important parameters.

2.1 Functional Classification

Roads fulfill different functions based on traffic type and application level. In this study, Sheridan County's road network was divided into functional classifications. Table 1 shows the general classes of gravel roads while Table 2 shows the mileages in each functional class. It is clear from Table 2 that a large percentage of Sheridan County's roads can be classified as local roads. Fifteen miles of gravel roads are classified as industrial and 30 miles are classified as collectors. Tables 3 and 4 have the same information for asphalt roads. Lower Prairie Dog Road is assigned to the industrial class. Additional roads will probably be assigned to this class as more information becomes available. For the non–industrial roads, the top widths measured as part of the asset management program were used to approximate the functional classes. A basic problem with this approach occurs on roads that are not wide enough to carry their traffic volume. Correctly assigning functional classes based on traffic loads will solve this problem. A high percentage of the roads in Sheridan County are unpaved. These unpaved roads can be impacted more severely by the heavy gas drilling traffic.

Table 1. Gravel Roads Functional Classifications

Class	Top Width Range	Traffic Types
Seasonal	≤10'	Two–tracks
Access	11' – 13'	Agricultural and recreational access
Local	14' – 20'	Residential and light industrial
Collector	≥21'	Heavy residential and industrial
Industrial	NA	Heavy truck traffic

Table 2. Gravel Road Mileages by Functional Classification

Seasonal	Access	Local	Collector	Industrial	TOTAL
37	88	307	30	15	477

Table 3. Asphalt Roads Functional Classifications

Class	Top Width Range	Traffic Types
Local	≤19'	Residential and light industrial
Collector	20' – 23'	Medium residential and industrial
Arterial	≥24'	Heavy residential and industrial
Industrial	NA	Heavy truck traffic

Table 4. Asphalt Road Mileages by Functional Classification

Local	Collector	Arterial	Industrial	TOTAL
4	20	8	0	32

2.2 Surface Conditions: Surfacing Serviceability Index (SSI)

An overall road rating, referred to as the surfacing serviceability index (SSI), was needed to determine the condition of each road segment in Sheridan County. This section describes the SSI calculations for gravel and asphalt roads.

2.2.1 Gravel Roads

In this study, road repair needs were estimated based on their current conditions. During the asset management data collection, a number of variables that do not directly impact the quality of the road were collected, such as drainage, crown, and gravel quality. However, only those variables that directly influence the quality of the road from the traveling public's perspective were used to determine if repairs are needed. These variables are shown in Table 5 for gravel roads. The SSI already established was calculated for each gravel road segment based on the weight factors summarized in Table 5.

Table 5. Gravel Roads SSI: Distress Weights

Distress	Overall Condition	Loose Aggregate	Potholes	Washboards	Rutting	Dust
Weight	9%	5%	37%	32%	14%	3%

2.2.2 Asphalt Roads

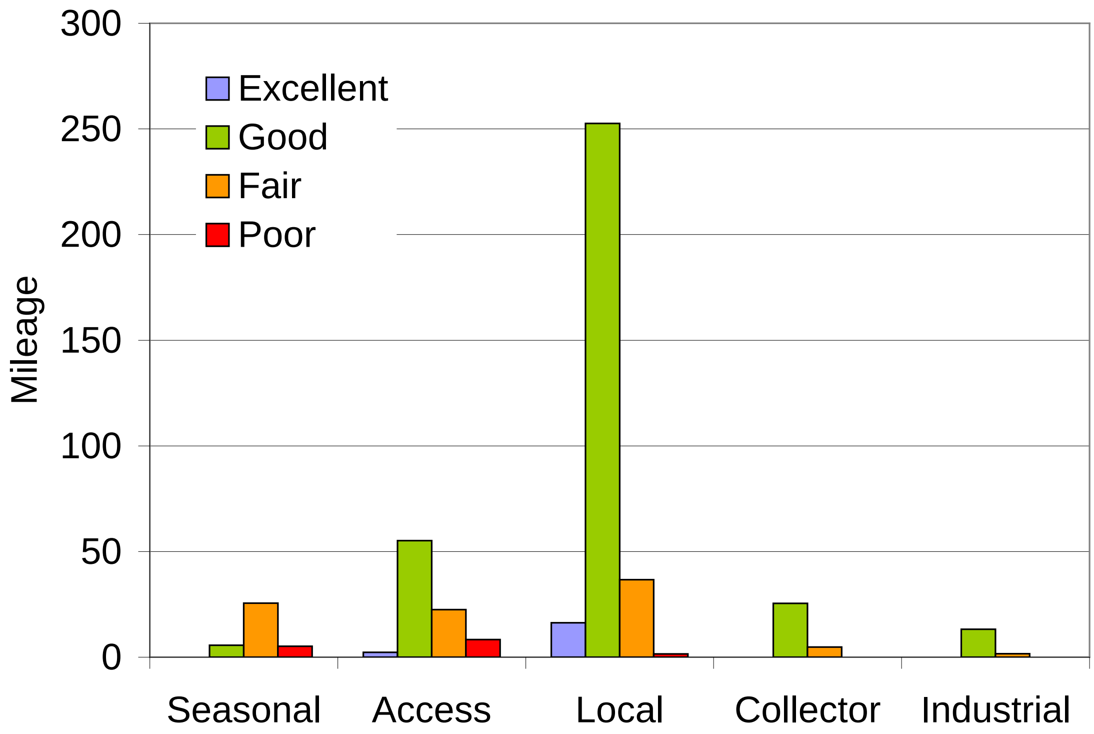
A similar process was used to determine the SSI for paved roads. Table 6 shows the distresses and weights used to establish the SSI for asphalt segments.

Table 6. Asphalt Roads SSI: Distress Weights

Distress	Overall Condition	Rutting	Distortion	Patching	Potholes	Aging Cracks	Fatigue Cracks
Weight	10%	13%	3%	16%	40%	7%	11%

3. SURFACING CONDITIONS: GRAVEL ROADS

The road condition information collected in 2005 was used to calculate the SSI of all gravel road segments in Sheridan County. Figure 1 shows the fraction of gravel roads in each functional class that are in each surfacing condition. The seasonal and access roads have little mileage and carry very little traffic, so they are not of any great concern. The problem is with the local, collector, and industrial classes that carry the vast majority of traffic on the county's gravel roads. Approximately 22% of these roads are in fair or poor condition.



• Figure 1. Gravel Roads Surfacing Serviceability Index

Of greatest concern are those roads with an SSI of fair in the collector and industrial classes. The roads in this category comprise 1⅓% of the county's gravel roads. Another concern is the local and access roads in poor condition, which comprise 2% of the county's gravel roads. Worse conditions can be tolerated on the local and access roads since they generally carry less traffic at lower speeds.

Figure 2 shows the portion of Sheridan County's 30 miles of collector roads that are in fair condition or worse. Sixteen percent of the roads in this higher traffic volume class are in substandard condition. These roads gather traffic from local roads and transfer them to asphalt county and state roads. From an engineering standpoint, the drop–off in quality from the paved roads to some of these gravel collector roads is often too great. The roads in this classification that are in fair condition should be upgraded.

Figure 2 also shows the condition of Sheridan County's 15 miles of gravel roads currently classified as industrial, all on Lower Prairie Dog Road. Eleven percent of them are in substandard condition. This road carries significant heavy truck traffic, which makes it particularly vulnerable to excessive and sometimes irreparable damage. It currently receives frequent maintenance, and paving this road should be considered. It needs a lot of maintenance to keep it in acceptable condition and would benefit from structural and surfacing improvements to help it carry increasingly heavy loads. If improvements are not made quickly, more expensive work may be needed in the near future.

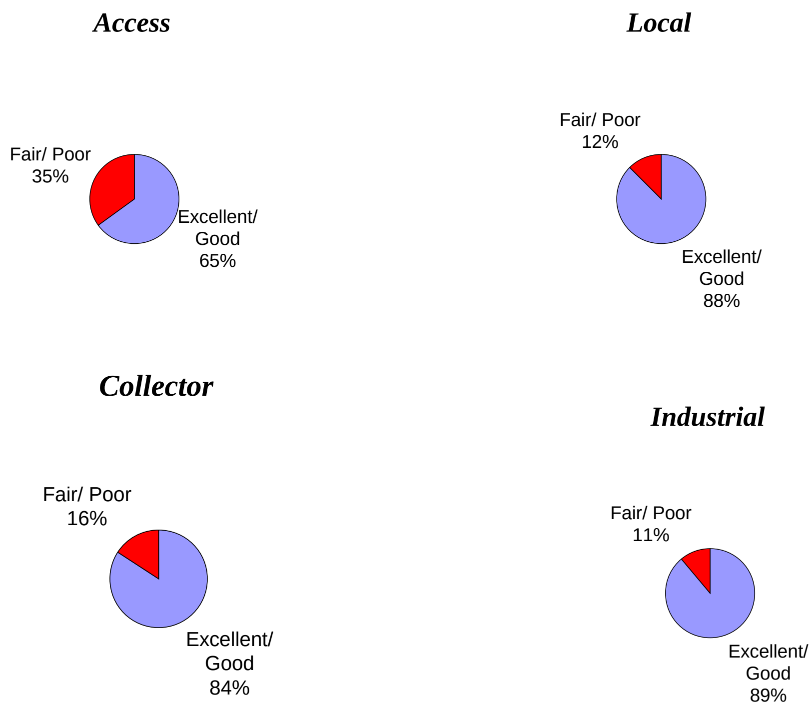


Figure 2. Gravel Road Conditions

The condition of the local roads, as shown in Figure 2, is similar to that on the collector and industrial roads. There are 307 miles of local roads compared with 45 miles of collector and industrial roads, but they carry less traffic so they don't deteriorate as quickly. Also, they are not expected to be in as good a condition as the higher volume collector and industrial roads. The class of road implies that the situation is not as urgent as for the higher volume roads, but the greater mileage in this class demands that it receive attention as well, particularly those in poor condition.

Figure 2 shows that about one–third of the access roads are in fair or poor condition. The roads in this class generally carry less traffic than those in the higher classes, though the classification of these roads needs to be more closely scrutinized. Some of these roads should probably be reclassified as local roads, in which case those in fair condition should be considered for improvements. Those in poor condition should be considered for improvements.

4. BUDGET NEEDS OF GRAVEL ROADS

4.1 Condition Driven Needs

Probably the top priority for Sheridan County's gravel roads is maintaining the 44 miles of local, collector, and industrial roads in fair condition. The potential for these roads to fall into further disrepair is considerable. These roads are in marginal condition, and sufficient maintenance needs to be undertaken to get these roads into good condition, particularly those that receive higher traffic volumes.

There are seven miles of higher volume roads in the collector and industrial classes in fair condition. These should be improved. Sheridan County is fortunate that it doesn't have any of these higher volume roads in poor condition. However, these seven miles need to be maintained in at least their current condition so they don't deteriorate to the point where they need expensive repairs. Data received from the South Dakota DOT compared the cost of structural upgrades – regrading the surface, adding 4 in. of gravel, and cleaning ditches and culverts – to the cost of rebuilding the road with 6 in. of gravel. Adjusted for inflation, the structural upgrades cost around $32,000 per mile while rebuilding cost around $260,000 per mile. In general terms, roads in fair condition can receive the less expensive treatment and perform adequately, but if they are allowed to deteriorate too much, it may be necessary to undertake more expensive repairs.

For the seven miles of collector and industrial roads in fair condition, it isn't too late to make relatively inexpensive repairs to maintain them in adequate condition. Structural upgrades to these seven miles would cost about $200,000. However, if these roads deteriorate to the point where they must be rebuilt, the cost may jump to $1,700,000. While Sheridan County's higher volume roads are in relatively good shape now, money must be spent to maintain these roads or costs could escalate dramatically.

Table 7. Needed Repairs to Gravel Roads

	Seasonal	Access	Local	Collector	Industrial	Total
Maintenance	$7,202	$167,482	$154,905	$48,876	$0	$378,464
Construction	$0	$0	$532,037	$0	$0	$532,037
Totals	$7,202	$167,482	$686,942	$48,876	$0	$910,501

The bottom line is this: Spending $0.2 million on these roads now could easily prevent a $1.7 million expense in the near future. You can pay now or you can pay a lot more later.

4.2 Safety and Geometric Needs

On top of the surfacing concerns described above, there are safety concerns. The asset management program does not address geometric problems such as dangerous curves, dangerous intersections, insufficient clear zones (empty space on the side of the road that gives a driver a chance to recover when a vehicle leaves the roadway), and roads too narrow to carry their traffic volume. Reconstructing these roads to make them safer is a major expense that has not been fully addressed in this report due to insufficient information, but this should not be construed to imply that such problems don't exist. It is highly recommended that a future study should be performed to evaluate the needs in this area.

4.3 Annual Construction and Routine Maintenance Needs

Based on the limited data available, average construction costs were estimated. Table 8 shows routine annual construction costs of $3.8 million. Table 8 estimates the cost of maintaining the county road network in acceptable condition, while the construction costs reflect the annual costs for the foreseeable future to bring substandard roads up to acceptable conditions. It is clear from Table 8 that over $5 million is needed annually.

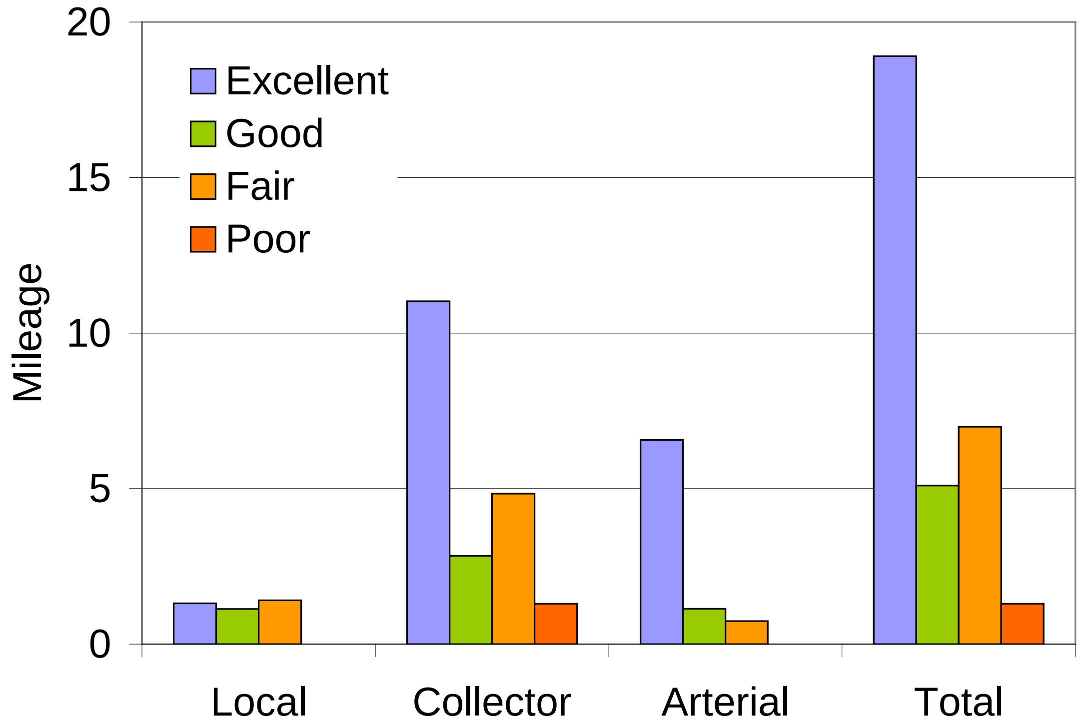
Table 8. Annual Gravel Roads Construction and Routine Maintenance Costs

	Seasonal	Access	Local	Collector	Industrial	TOTAL
Mileage	37	88	307	30	15	477
Maintenance Cost/Mile	$135	$825	$2,721	$6,188	$9,179	$2,592
Construction Cost/Mile	$0	$0	$5,000	$52,500	$48,000	$8,040
Maintenance	$4,958	$72,925	$835,627	$187,419	$136,224	$1,237,153
Construction	$0	$0	$1,535,274	$1,590,069	$712,392	$3,837,735

5. SURFACING CONDITIONS: ASPHALT ROADS

Figure 3 shows the fraction of asphalt roads in each functional class that are in each surfacing condition. The local roads are in fair condition or better and not much of a problem. However, the problem is with the collector class which carries more traffic. Nearly a third of the collector roads are in fair or poor condition.

Figure 4 shows that 9% of the asphalt arterial roads are in fair or poor condition. These higher volume roads should be in good condition. Those that aren't should be improved on a systematic basis.



• Figure 3. Surfacing Serviceability Index: Asphalt Roads

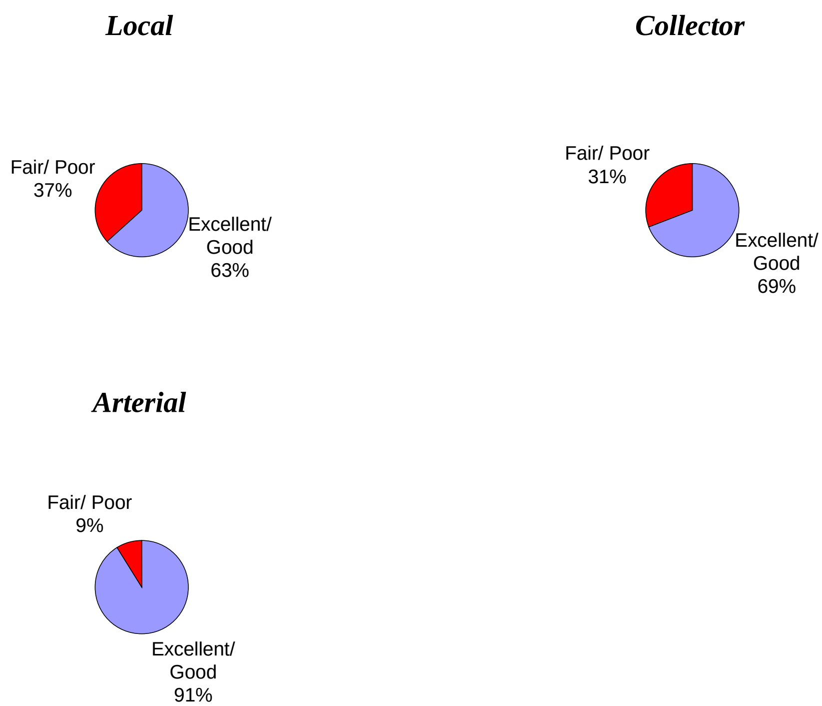


Figure 4. Asphalt Roads Conditions

About 31% of the asphalt collector roads are in fair or poor condition; these roads need immediate attention. Over a third of the asphalt local roads are in less than good condition; the situation is not as serious as it is for the higher volume roads. With less traffic, local roads don't deteriorate as fast and the financial impacts of roads carrying less traffic is less than for those that carry more vehicles.

6. BUDGET NEEDS OF ASPHALT ROADS

6.1 Condition Driven Needs

After determining the current conditions of all asphalt sections in Sheridan County, the total repair costs were estimated and summarized in Table 9. The method used for asphalt segments was similar to the one described earlier for gravel segments.

Table 9. Needed Repairs to Asphalt Roads

	Local	Collector	Arterial	TOTAL
Miles Repaired	0	3.6	0	3.6
Repair Cost/Mile Repaired	$0	$200,000	$0	$200,000
Total Repair Costs	$0	$729,794	$0	$729,794

6.2. Safety and Geometric Needs

On top of the surfacing concerns described above are safety concerns. The asset management program does not address geometric problems such as dangerous curves, dangerous intersections, insufficient clear zones, and roads too narrow to carry their traffic volume. Reconstructing these roads to make them safer is a major expense that has not been fully addressed in this report due to insufficient information, but this should not be construed to imply that such problems don't exist. It is highly recommended that a future study should be performed to evaluate the needs in this area.

6.3. Annual Construction and Routine Maintenance Needs

The annual construction and routine maintenance needs for asphalt segments were calculated using methods similar to those used for gravel segments, as summarized in Table 10.

Table 10. Annual Asphalt Roads Construction and Routine Maintenance Costs

	Local	Collector	Arterial	Total
Mileage	4	20	8	32
Maintenance Cost/Mile	$9,376	$11,026	$14,276	$11,680
Construction Cost/Mile	$1,100	$7,000	$13,500	$7,997
Maintenance	$36,072	$220,543	$120,588	$377,203
Construction	$4,232	$140,012	$114,031	$258,276

7. SIGNS CONDITION AND BUDGET NEEDS

The sign panel and post conditions were rated as part of the asset management data collection. Figure 5 shows these conditions.

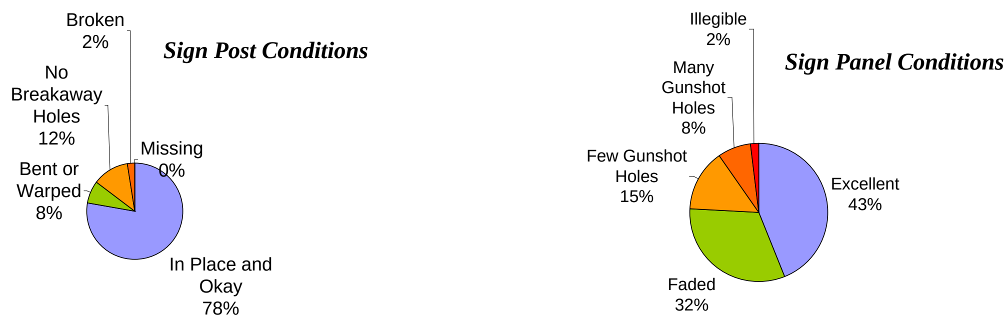


Figure 5. Sheridan County Sign Conditions

Estimates of the annual sign routine maintenance costs were made, as shown in Table 11. Using the condition data collected during the asset management program, estimates of the needed repairs to Sheridan County signs were made. Table 12 contains these estimated repair needs.

Table 11. Routine Annual Sign Maintenance Costs

	count/sf	Cost
Replace Panel	299.4	$22,452
Replace Post	42	$16,762
Replace Sheeting	598.7	$29,936
	Total	$69,149

Table 12. Sign Repair Needs

	count/sf	Cost
Replace Panel	723.9	$21,716
Replace Post	87	$17,400
Replace Sheeting	2699.1	$53,982
Drill Breakaway Holes	108	$5,400
	Total	$98,498

The situation with sign repair and replacement may change in the near future. The Federal Highway Administration (FHWA) plans to issue requirements for sign maintenance. Installation of new signs and replacement of many substandard signs may be required, significantly increasing these estimates.

8. CATTLEGUARDS CONDITION AND BUDGET NEEDS

This study rated 252 cattleguards, 149 on the mainline and 103 on approaches. Figure 6 shows the cattleguards' conditions. Estimates of annual routine maintenance costs for cattleguards were conducted. Table 13 contains these estimates.

Based on the condition ratings performed during the asset management data collection, estimates of the repairs needed to bring all cattleguards up to adequate conditions are shown in Table 14.

Table 13. Routine Cattleguard Maintenance Activities and Annual Costs

Activity	Cattleguards Maintained per Year	Cost
Replace Grate	6	$4,725
Replace Base	6	$9,450
Clean Base	21	$4,200
Repair Wing Fence	8	$1,680
Repair Approach	50	$10,080
	TOTAL	$30,135

Table 14. Needed Cattleguard Repairs

Activity	Cattle guards	Cost
Replace Grate	20	$15,000
Replace Base	15	$22,500
Clean Base	30	$6,000
Repair Wing Fence	43	$8,600
Repair Approach	16	$3,200
	TOTAL	$55,300

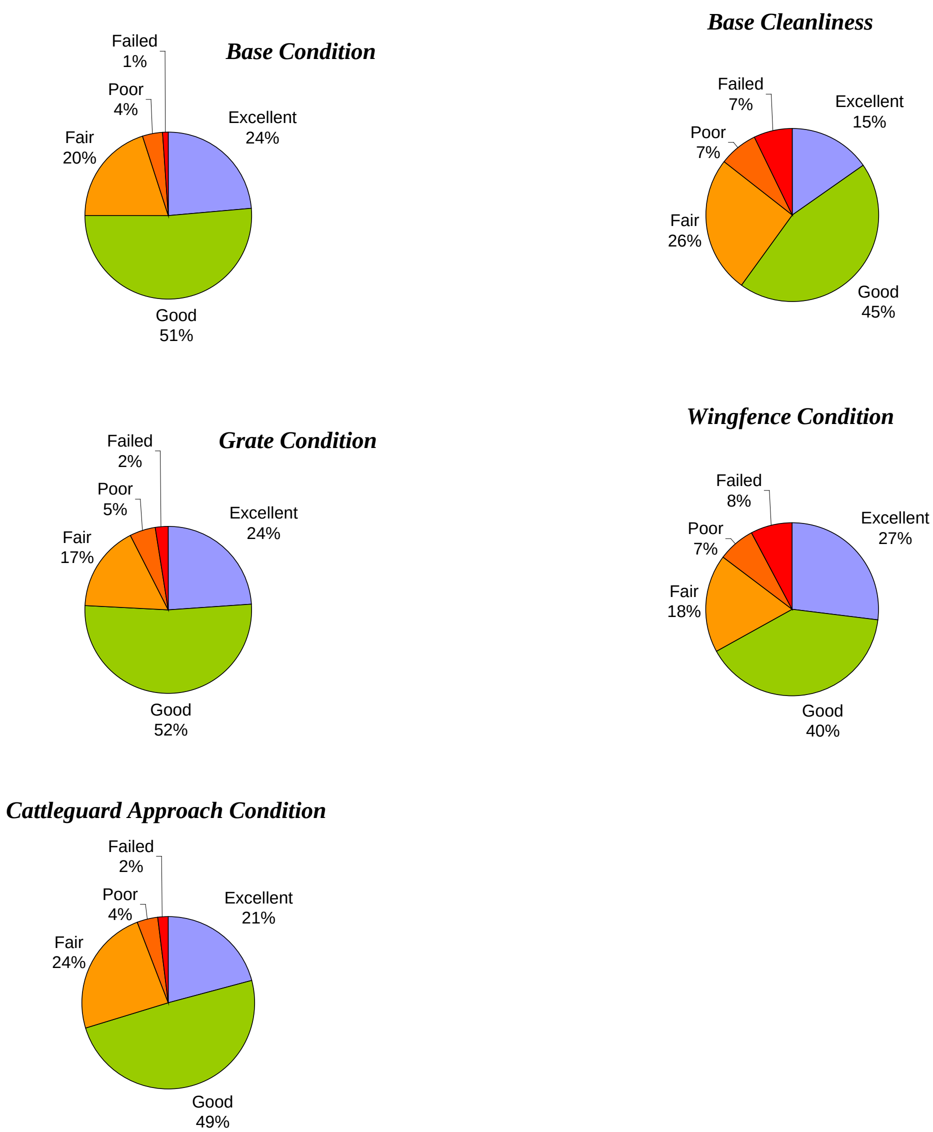


Figure 6. Cattleguard Conditions

9. CULVERTS CONDITION AND BUDGET NEEDS

As part of the asset management program, the condition and cleanliness of 2,081 culverts in Sheridan County were rated. Maintaining culverts in good condition is necessary both for structural support of the overlying road and to carry water during a precipitation event, particularly flash floods. When culverts are installed, they should be sized to provide enough flow to carry water during a flash flood, thus preventing washout of the overlying road. When culverts get clogged, a heavy precipitation event may wash out the road. Figure 7 shows the condition and cleanliness of the Sheridan County culverts.

The costs of maintaining, cleaning, and periodically replacing culverts throughout the county have been estimated. The results of these estimates are in Table 15.

The unmet repair and replacement needs for Sheridan County culverts were also estimated, based on the culverts' current condition and cleanliness. The results of these estimates are summarized in Table 16.

Table 15. Culvert Annual Routine Maintenance and Replacement Costs

Activity	Cost
Replace Culverts	$218,104
Repair Culverts	$86,519
Clean Culverts	$43,557
Total	$348,180

Table 16. Needed Culvert Repair and Cleaning Costs

Activity	Cost
Replace Culverts	$471,790
Repair Culverts	$216,430
Clean Culverts	$10,025
Total	$698,245

These tables show that the county is about two years behind in repairing and replacing their culverts.

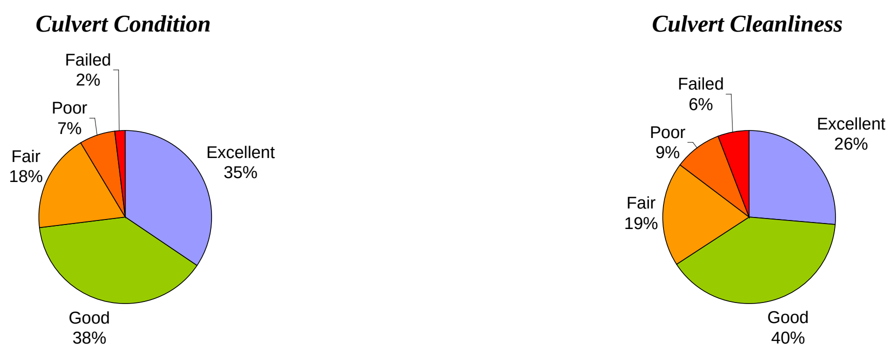


Figure 7. Sheridan County Culverts

10. SUMMARY AND CONCLUSIONS

The costs of maintaining and upgrading county roads are high. While most county road and bridge departments in the state are probably underfunded, those in Sheridan County will be hit particularly hard, largely due to drilling impacts.

This report is based on information obtained at this juncture, the second year of a three-year project. Though more accurate and detailed information will be available by the study's conclusion, it is quite apparent that these roads need attention now. In section 4.1, it was stated that a $0.2 million investment now might avoid the necessity of a $1.7 million expense in the not very distant future, an eight-to-one return on investment. Though the asset management program only addresses defects of the roads' surfaces, there are greater unmet needs brought about by inadequate roadway geometries.

Figure 8 and Table 17 estimate the repairs needed to Sheridan County roads. The asphalt and gravel repairs values address repairs needed due to surface conditions, but not repairs needed to correct geometric deficiencies that result in unsafe conditions. Also, bridge repairs are not considered in this estimate.

Figure 9 and Table 18 show the estimated routine annual costs. These costs are split into maintenance and construction costs. The maintenance costs are based on the inventory performed as part of the asset management system along with estimates of the maintenance activities performed, their costs, and the frequency at which they are to be performed for roads in each functional class. The construction costs are based on estimates of the portion of the roads that need construction on an annual basis. Most of this reconstruction is driven not by surface defects, but rather by geometric insufficiencies that cause the roads to be unsafe.

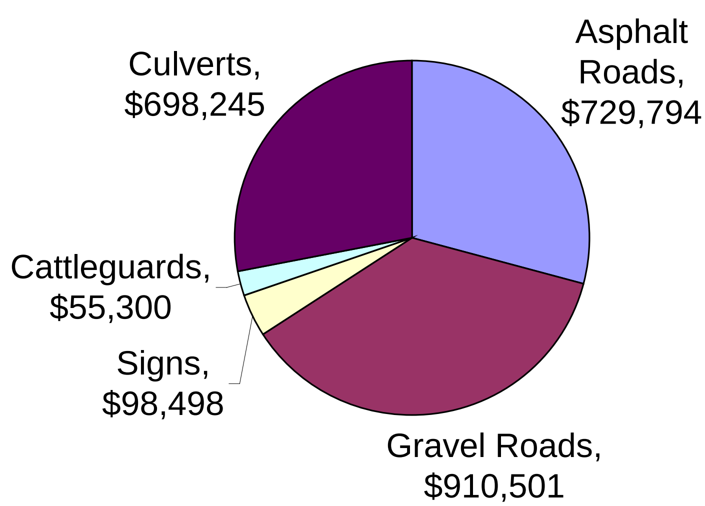


Figure 8. Sheridan County Unmet Repair Needs

Table 17. Unmet Repair Needs

Asphalt Roads	$729,794
Gravel Roads	$910,501
Signs	$98,498
Cattleguards	$55,300
Culverts	$698,245
TOTAL	$2,492,338

Table 18. Annual Construction and Routine Maintenance Costs

Asphalt Roads: Maintenance	$377,203
Asphalt Roads: Construction	$258,276
Gravel Roads: Maintenance	$1,237,153
Gravel Roads: Construction	$3,837,735
Signs	$69,149
Cattleguards	$30,135
Culverts	$348,180
TOTAL	$6,157,831

There are significant benefits to having good roads, both in economic terms and in terms of human lives. This preliminary report provides some guidance as to the magnitude of the costs of adequately maintaining Sheridan County's roads.

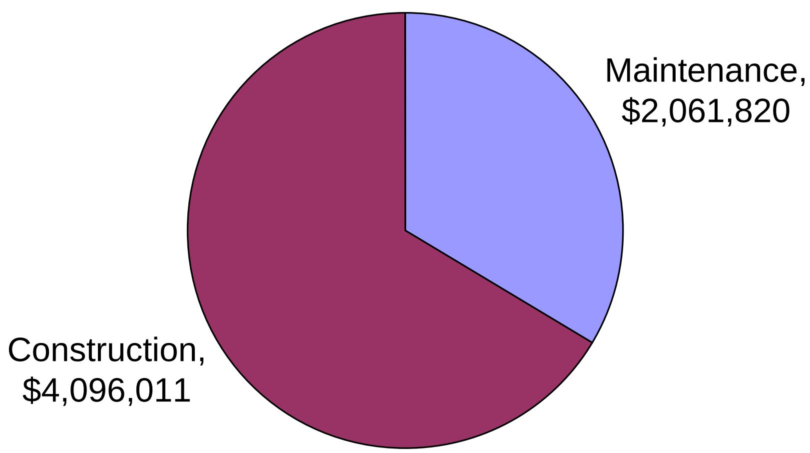


Figure 9. Routine Annual Costs

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ASSET MANAGEMENT FOR WYOMING COUNTIES

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Volume III of III

Appendices

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August 2011

A.1 EVALUATION AND RATING MATERIALS

The following pages show some of the slides used as part of the data collector training process. These slides demonstrate the rating standards used in this study. About one full day of training with these and other slides in the classroom was followed by a second day in the field practicing the rating and evaluation techniques learned in the classroom, along with the software operational processes. The complete slide shows used during training are on the accompanying CD. Contact George Huntington at georgeh@uwyo.edu to receive a copy of this 200MB file.

- Culverts
  - Conditions: pp. 2 – 3
  - Cleanliness/Flow: pp. 4 – 5
- Signs
  - Panels: pp. 6 – 7
  - Supports: pp. 7 – 8
- Cattleguards
  - Grate conditions: pp. 8 – 9
  - Base conditions: pp. 9 – 10
  - Base cleanliness: pp. 11 – 12
  - Wingfence condition: pp. 12 – 13
  - Approach condition: pp. 13 – 14
- Gravel Roads
  - Dust: pp. 14 – 15
  - Washboards: pp. 15 – 16
  - Potholes: pp. 16 – 18
  - Rutting: pp. 18 – 19
  - Loose aggregate: pp. 19 – 20
  - Crown: pp. 20 – 22
  - Drainage: pp. 22 – 26
  - Gravel Quality: pp. 26 – 29
  - Gravel Sufficiency: pp. 29 – 31
- Asphalt Roads
  - Raveling: pp. 31 – 32
  - Flushing: pp. 32 – 33
  - Rutting: p. 33
  - Distortion: pp. 33 – 34
  - Transverse Cracking: pp. 34 – 35
  - Reflection Cracking: p. 35
  - Slippage Cracking: p. 35
  - Longitudinal Cracking: pp. 35 – 36
  - Block Cracking: pp. 36 – 37
  - Alligator/Fatigue Cracking: pp. 37 – 38
  - Patching: pp. 38 – 39
  - Potholes: p. 40
  - Overall: pp. 40 – 44

A.2 DATA DICTIONARY: METADATA

The following pages show the data fields – metadata – filled during the data collection process undertaken in this study. An alternate version is found on the CD as C:\Asset_Mgmt\GIS_Data\WY_Assets_GeodatabaseReport.htm.

Asphalt

ID ....ID

ID assigned to road segment. For example, SH124–01 (Sheridan County, Road Number 124, Segment 1) starting with segment 00.

Road Name...ROADNAME

Name of the road.

Road Number ....ROADNUMBER

Number of the road data is being collect on.

Date ....DATE_COLL

Date on which data was collected.

Top Width ....TOPWIDTH

Measure of top width (ft).

Crown Slope..CROWNSLOPE

Slope of the crown (in / 4 feet).

PASER ....PASER

The overall PASER rating for the segment. Values collected:

- 10 – Excellent
- 9 – Excellent
- 8 – Very Good
- 7 – Good
- 6 – Good
- 5 – Fair
- 4 – Fair
- 3 – Poor
- 2 – Very Poor
- 1 – Failed
- 0 – Not Rated (Default Value)

Drainage ....DRAINAGE

The overall drainage rating for a segment based on the data collector's subjective judgment and reported in values from 0 to 10.

- 10 – Excellent
- 8 – Good
- 6 – Fair
- 4 – Poor
- 2 – Failed
- 0 – Not Rated (Default Value)

Polishing .... POLISHING

The amount of polishing present in a segment based upon examples given in the PASER Manual and the data collector's subjective judgment. Values collected were:

1 – None
2 – Low
3 – Medium
4 – High
0 – Not Rated

Ravelling .... RAVELLING

The amount of raveling present in a segment based upon examples given in the PASER manual and the data collector's subjective judgment. Values collected were:

1 – None
2 – Low
3 – Medium
4 – High
0 – Not Rated

Flushing .... FLUSHING

The amount of flushing present in a segment based upon the PASER manual and the data collector's subjective judgment. Values collected were:

1 – None
2 – Low
3 – Medium
4 – High
0 – Not Rated

Rutting .... RUTTING

The depth and extent of rutting present in a segment based on examples given in the PASER manual and the data collector's subjective judgment. Values collected were:

1 – None
2 – Low (< 1")
3 – Medium (1" – 2")
4 – High (> 2")
0 – Not Rated

Distortion .... DISTORTION

The amount of distortion on a road segment based upon examples in the PASER manual and the data collector's subjective judgment. Values recorded were:

1 – None
2 – Low
3 – Medium
4 – High
0 – Not Rated

Patching .... PATCHING

The amount and quality of patching present in a road segment based upon the data collector's subjective judgment and examples given in the PASER manual. Values recorded were:

1 – None
2 – Low
3 – Medium
4 – High
0 – Not Rated

Potholes .... POTHOLES

The amount and severity of potholes present in a segment based on the data collector’s subjective judgment and examples provided in the PASER manual. Values recorded were:

1 – None
2 – Low
3 – Medium
4 – High
0 – Not Rated

Transverse Cracking .... TRANSV_CRK

The size and frequency of transverse cracks present in a segment. Values recorded were:

1 – None
2 – Low (<¼”)
3 – Medium (¼” – ½”)
4 – High (> ½”)
0 – Not Rated

Reflective Cracking .... REFLCT_CRK

The size and frequency of reflective cracks in a segment. Values recorded were:

1 – None
2 – Low (<¼”)
3 – Medium (¼” – ½”)
4 – High (> ½”)
0 – Not Rated

Slippage Cracking .... SLIPPG_CRK

The size and frequency of slippage cracks present in a segment. Values recorded were:

1 – None
2 – Low (<¼”)
3 – Medium (¼” – ½”)
4 – High (> ½”)
0 – Not Rated

Longitudinal Cracking .... LONGIT_CRK

The size and frequency of longitudinal cracks on a segment. Values recorded were:

1 – None
2 – Low (<¼”)
3 – Medium (¼” – ½”)
4 – High (> ½”)
0 – Not Rated

Block Cracking .... BLOCK_CRK

The size and frequency of block cracking on a segment. Values recorded were:

1 – None
2 – Low (<¼”)
3 – Medium (¼” – ½”)
4 – High (> ½”)
0 – Not Rated

Alligator Cracking .... ALLIGA_CRK

The size and frequency of alligator cracking on a segment. Values recorded were:

1 – None
2 – Low (<¼")
3 – Medium (¼" – ½")
4 – High (> ½")
0 – Not Rated

Recent Maintenance Activities .... ACTIVITY

A description of recent maintenance activities performed on the segment. This data is collected from information provided by the maintainers.

Comments .... COMMENT

Miscellaneous comments made by the data collectors about the segment.

Photo .... PHOTO

Name of photo taken for the particular segment.

Gravel Sections

ID .... ID
Date .... DATE_COLL
Road Name .... ROADNAME
Road Number .... ROADNUMBER
PASER .... PASER

The overall PASER Rating for the segment. Based on examples given in the PASER manual as well as the data collector's subjective judgment.

Top Width .... TOPWIDTH

The top width of the road segment (ft).

Crown Slope .... CROWNSLOPE

Measure of the crown of the road (in/4ft).

Loose Aggregate .... LOOSEAGG

The relative amount of loose aggregate found on a road segment. Values recorded were:

10 – Excellent (No loose aggregate)
8 – Good
6 – Fair
4 – Poor
2 – Failed (Mostly loose aggregate)
0 – Not Rated (Default Value)

Potholes .... POTHOLES

The relative amount of loose aggregate found on a road segment. Values recorded were:

10 – Excellent (No potholes)
8 – Good
6 – Fair
4 – Poor
2 – Failed (Constant potholes)
0 – Not Rated (Default Value)

Gravel Sufficency .... GRVL_SUFF

The sufficiency of gravel on a road segment.

10 – Excellent (Well graded, dense, compacted gravel in sufficient quantity to handle traffic loads)
8 – Good
6 – Fair
4 – Poor

2 – Failed (Gravel completely contaminated by sub grade)
0 – Not Rated (Default Value)

Gravel Quality.. GRVL_QUAL

The quality of gravel on a road segment.

10 – Excellent (Well graded, dense, compacted gravel in sufficient quantity to handle traffic loads)
8 – Good
6 – Fair
4 – Poor
2 – Failed (Gravel completely contaminated by sub grade)
0 – Not Rated (Default Value)

Washboards.. WASHBOARDS

The relative amount of washboarding present on a road segment. Values recorded were:

10 – Excellent (No washboards)
8 – Good
6 – Fair
4 – Poor
2 – Failed (Constant washboarding)
0 – Not Rated (Default Value)

Crown.. CROWN

The condition of the crown on the road segment. The values recorded were:

10 – Excellent
8 – Good
6 – Fair
4 – Poor
2 – Failed
0 – Not Rated (Default Value)

Rutting .... RUTTING

The relative amount of rutting found on the segment. Values recorded were:

10 – Excellent (No rutting)
8 – Good
6 – Fair
4 – Poor
2 – Failed (Nearly impassable)
0 – Not Rated (Default Value)

Drainage.. DRAINAGE

The condition of the drainage of the segment. Values recorded were:

10 – Excellent
8 – Good
6 – Fair
4 – Poor
2 – Failed
0 – Not Rated (Default Value)

Dust.. DUST

The amount of dust present after a vehicle passed at 30 mph. Values recorded were:

10 – Excellent (No dust)
8 – Good
6 – Fair
4 – Poor
2 – Failed (No visibility)
0 – Not Rated (Default Value)

Surface Comments .... COMMENTS

Data collector's comments on the general condition of the surface.

Photo .... PHOTO

The name of the photo of the segment.

Culverts

ID .... ID

Road Name .... ROADNAME

Road Number .... ROADNUMBER

Date .... DATE_COLL

Type .... TYPE

Type of culvert. Values recorded were:

1 – CMP
2 – RCP
3 – CIP
4 – Plastic
5 – Unknown
6 – Other
0 – Not Rated

Diameter .... DIAM_IN

Diameter of the round culvert(s) (in).

Length .... LENGTH_FT

Length of the culvert(s) (ft).

Shape .... SHAPE_CULV

Shape of the culvert(s). Values recorded were:

1 – Round
2 – Box
3 – Elliptical
4 – Other
5 – Unknown
0 – Not Rated

Height .... HEIGHT_IN

Height of culverts that are not round (in).

Width .... WIDTH_IN

Width of culverts that are not round (in).

Cover .... COVER_IN

The amount of cover over the culvert (in).

Number .... NUMBER_AMT

The number of culverts observed at a location.

Condition .... CONDITION

The overall condition of the culvert(s). Values recorded were:

10 – Excellent
8 – Good
6 – Fair
4 – Poor
2 – Failed
0 – Not Rated (Default Value)

Cleanliness .... CLNLINESS

The relative cleanliness of the culvert(s). Values recorded were:

10 – Excellent (Completely clear of obstructions)
8 – Good
6 – Fair
4 – Poor
2 – Failed (Completely plugged)
0 – Not Rated (Default Value)

Photo ....PHOTO

The name of the photo that shows the culvert(s).

Comments .... COMMENTS

Data collector's comments on the culvert(s).

Signs and Sign Supports

General Info

ID ....ID
Date...DATE_COLL
Road Name...ROADNAME
Road Number ....ROADNUMBER
Side of Road..SIDE

Side of the road the sign is located on relative to increasing mileposts.

Signs (All the same):

MUTCD Code.. S1MUTCD, S2MUTCD, S3MUTCD

MUTCD code assigned to sign type.

Description..S1DESC, S2DESC, S3DESC

Brief description of sign.

Height..S1HEIGHT, S2HEIGHT, S3HEIGHT

Height of sign (in).

Width S1WIDTH, S2WIDTH, S3WIDTH

Width of sign (in).

Sign Condition S1COND, S2COND, S3COND

The overall condition of the sign. Values recorded were:

10 – Excellent
8 – Faded, No Gunshots
6 – Few Gunshot Holes
4 – Many Gunshot Holes
2 – Illegible
0 – Not Rated (Default Value)

Comments S1COMMENTS, S2COMMENTS, S3COMMENTS

Data collector's general comments on sign.

Support

Number of Supports .... SUPP_COUNT

The number of supports.

Support Type .... SUPPTYPE

The type of support in use. Values collected were:

1 – Steel
2 – Wood
3 – Other
0 – Not Rated

Base Type .... BASETYPE

Describes the base of the sign support. Values collected were:

1 – Earth
2 – Concrete
3 – Other
0 – Not Rated

Support Condition .... CONDITION

A rating of the sign support's overall condition. Values collected were:

10 – In Place and Okay
8 – Bent or warped
6 – No Break Away Holes
4 – Broken
2 – Missing
0 – Not Rated (Default Value)

Comments .... COMMENTS

Data collector's general comments on the sign support.

Photo .... PHOTO

The name of the photo showing the sign(s)/sign supports

Approaches

ID .... ID
Date .... DATE_COLL
Road Name .... ROADNAME
Road Number .... ROADNUMBER
Side .... SIDE

Which side of the road the approach is on relative to increasing mileposts.

Width at .... WIDTH_AT

Where the width of the approach was measured. Values collected were:

1 – Fence
2 – 40 feet from traveled way
3 – Cattleguard
4 – Top Width
0 – Not Rated

Width .... WIDTH_FT

Width of the approach in feet.

Gate .... GATE

What type of gate, if any, is present on the approach. Values collected were:

1 – Cattleguard
2 – Steel
3 – Wire
4 – Wood
5 – None
6 – Other
0 – Not Rated

Approach ....APPROACH

Describes the type of approach. Values collected were:

1 – Residential
2 – Field
3 – Drilling
4 – Mining
5 – Construction
6 – Unknown
7 – Other
0 – Not Rated

Comments .... COMMENTS

Data collector's general comments about the approach.

Photo ....PHOTO

The name of the photo which shows the approach.

Cattleguards

ID ....ID

Date ....DATE_COLL

Road Name...ROADNAME

Road Number ....ROADNUMBER

Width ....WIDTH_FT

Width of the cattleguard (ft). Measured parallel to the traveled way.

Length .... LENGTH_FT

Length of the cattleguard (ft). Measured perpendicular to the traveled way.

Location ....LOCATION

Describes the location of the cattleguard. Suggested values:

- Left
- Right
- Mainline

Grate Type ....GRATETYPE

Type of grate used in the cattleguard. Values collected were:

1 – Square Steel
2 – Round Steel
3 – Other
0 – Not Rated

Base Type..BASETYPE

Type of base used in the cattleguard. Values collected were:

1 – Concrete
2 – Wood
3 – Steel
4 – Other
0 – Not Rated

Grate Condition.. GRATECOND

The overall condition of the cattleguard grate. Values collected were:

10 – Excellent
8 – Good
6 – Fair
4 – Poor
2 – Failed
0 – Not Rated (Default Value)

Base Condition.. BASECOND

The overall condition of the cattleguard base. Values collected were:

10 – Excellent
8 – Good
6 – Fair
4 – Poor
2 – Failed
0 – Not Rated (Default Value)

Base Cleanliness .... BASECLEAN

The general cleanliness of the cattleguard base. Values collected were:

10 – Excellent
8 – Good
6 – Fair
4 – Poor
2 – Failed
0 – Not Rated (Default Value)

Wing Fence Condition ....WINGCOND

The condition of the wing fence. Values collected were:

10 – Excellent
8 – Good
6 – Fair
4 – Poor
2 – Failed
0 – Not Rated (Default Value)

Approach Condition.. APPRCHCOND

The condition of the approach (if applicable). Values collected were:

10 – Excellent
8 – Good
6 – Fair
4 – Poor
2 – Failed
0 – Not Rated (Default Value)

WYDOT Standard .... STANDARD

What, if any, WYDOT standards the cattleguard meets. Values collected were:

1 – HS–30 (5/16”)
2 – HS–20 (3/16”)
3 – Other/None
0 – Not Rated

Comments .... COMMENTS

Data collector’s general comments on the cattleguard.

Photo ....PHOTO

Name of the photo that shows the cattleguard.

Bridges

ID ....ID

Date..DATE_COLL

WYDOT ID ....WYDOT_ID

WYDOT ID given to the bridge (if applicable).

Photo ....PHOTO

Name of the photo showing the bridge.

Comments .... COMMENTS

Data collector’s general comments on the bridge.

Maintainer’s Information

Date..DATE_COLL

Road Name..ROADNAME

Road Number..ROADNUMBER

Beginning Point Description..BEGDESC

Description of the beginning point of the segment being described. For example, the intersection of US 270 and JO 222.

Ending Point Description..ENDDESC

Description of the ending point of the segment being described. For example, SH 124, mile marker 7.

Beginning Segment.. BEGSEG

The segment at which the maintainer’s information segment begins. This information is taken from the Asphalt or Gravel Section layers. For example, JO222–00.

Ending Segment.. ENDSEG

The segment at which the maintainer’s information segment ends. This is exactly like the like the beginning segment. For example, SH124–07.

Total ADT..TOTALADT

The total average daily traffic for the segment. Values collected were:

1 – V. Heavy, > 400
2 – Heavy, 150 – 400
3 – Moderate, 50 – 150
4 – Light, 5 – 50
5 – V. Light, < 5
0 – Not Rated

Heavy ADT..HEAVYADT

The total average daily traffic for heavy trucks on the segment. Values collected were:

1 – V. Heavy, > 200
2 – Heavy, 75 – 200
3 – Moderate, 25 –75
4 – Light, 5 – 25
5 – V. Light, < 5
0 – Not Rated

Any CBM Traffic..CBMTRAFFIC

Describes whether or not coal bed methane traffic occurs on the segment. Values collected were:

1 – Yes
2 – No
3 – Occasional
4 – Don't Know
0 – Not Rated

Aggregate

Source ....AGGSOURCE

The source of the aggregate used on the segment.

Material.. AGGMAT

What type of aggregate was used on the section. Values collected were:

1 – Crushed
2 – Pit Run
3 – RAP
4 – Other
0 – Not Rated

Size...AGGSIZE

The maximum size of the aggregate used in the segment. Values collected were:

1 – ¾"
2 – 1"
3 – 1 ½"
4 – 2"
5 – 3"
6 – 4"
7 – Other
0 – Not Rated

Gravel Placement

Most Recent .... GRVLDATE

The last date that gravel was placed on the segment. Values collected were:

- Date (MM/DD/YY)
- Don't Know
- Never

Frequency..GRVLFREQ

The frequency that gravel is placed on the section. Values collected were:

1 – 1 x / year
2 – 1 x / 2 yrs
3 – 1 x / 3 yrs
4 – 1 x / 4 yrs
5 – 1 x / 5 yrs
6 – 1 x / 7 yrs
7 – 1 x / 10 yrs
8 – < 1 x / 10 yrs

9 – Don’t Know
10 – Never
0 – Not Rated

Typical Thickness Added ....GRVLTHICK

The typical thickness added when gravel is placed on the segment. Values collected were:

1 – 1”
2 – 2”
3 – 3”
4 – 4”
5 – Other
6 – Don’t Know
0 – Not Rated

Maintenance

Surface and Crown Shaping Frequency..SFC_CROWN

The frequency of work done on the road surface/crown. Values collected were:

1 – ≥ 5 x / yr
2 – 4 x / yr
3 – 3 x / yr
4 – 2 x / yr
5 – 1 x / yr
6 – 1 x / 2 yrs
7 – 1 x / 3 yrs
8 – 1 x / 4 yrs
9 – ≤ 1 x / 5 yrs
10 – Don’t Know
11 – Never
0 – Not Rated

Pull Shoulder/Ditch Frequency...SHLDR_DITC

The frequency of pulling the shoulder/ditch of the road segment. Values collected were:

1 – 1 x / year
2 – 1 x / 2 yrs
3 – 1 x / 3 yrs
4 – 1 x / 5 yrs
5 – 1 x / 7 yrs
6 – ≤ 1 x / 8 yrs
7 – Don’t Know
8 – Never
0 – Not Rated

Dust Control

Most Recent ....DUSTDATE

The date of most recent placement of dust control materials. Values collected were:

– Date (MM/DD/YY)
– Don’t Know
– Never

Material..DUSTMAT

The dust control material applied to the section. Values collected include:

1 – MgCl
2 – Lignin
3 – Bentonite
4 – Other
0 – Not Rated

Frequency.. DUSTFREQ

The frequency at which dust control activities are performed. Values collected were:

1 – ≥ 2 x / year
2 – 1 x / year
3 – 1 x / 2 yrs
4 – 1 x / 3 yrs
5 – 1 x / 5 yrs
6 – 1 x / 7 yrs
7 – ≤ 1 x / 8 yrs
8 – Don't Know
9 – Never
0 – Not Rated

Material Rate...MATRATE

The rate at which the dust control was applied (specify units).

Material Dilution...MATDILUTE

The dilution of the dust control material that was applied.

Application Method .... DUSTMETHOD

The method used to apply the dust control material. Values collected were:

1 – Spray Only
2 – Spray and Blend
3 – Spray, Blend, and Compact
4 – Other
0 – Not Rated

Approaches

Most Recent .... APPRDATE

The date of most recent approach maintenance. Values collected were:

– Date (MM/DD/YY)
– Don't Know
– Never

Frequency...APPRFREQ

The frequency of approach maintenance on the segment. Values collected were:

1 – ≥ 2 x / year
2 – 1 x / year
3 – 1 x / 2 yrs
4 – 1 x / 3 yrs
5 – 1 x / 5 yrs
6 – 1 x / 7 yrs
7 – ≤ 1 x / 8 yrs
8 – Don't Know
9 – Never
0 – Not Rated

Mowing Frequency ....MOWFREQ

The frequency that mowing takes place on a segment. Values collected were:

1 – ≥ 5 x / yr
2 – 4 x / yr
3 – 3 x / yr
4 – 2 x / yr
5 – 1 x / yr
6 – 1 x / 2 yrs
7 – 1 x / 3 yrs
8 – 1 x / 4 yrs
9 – ≤ 1 x / 5 yrs
10 – Don't Know
11 – Never
0 – Not Rated

Spraying Weeds Frequency .... WEEDFREQ

The frequency that weed spraying takes place on a segment. Values collected were:

1 – ≥ 5 x / yr
2 – 4 x / yr
3 – 3 x / yr
4 – 2 x / yr
5 – 1 x / yr
6 – 1 x / 2 yrs
7 – 1 x / 3 yrs
8 – 1 x / 4 yrs
9 – ≤ 1 x / 5 yrs
10 – Don't Know
11 – Never
0 – Not Rated

Culvert Cleaning Frequency ....CLVRTCLEAN

The frequency that culvert cleaning occurs on the segment. Values collected were:

1 – ≥ 2 x / year
2 – 1 x / year
3 – 1 x / 2 yrs
4 – 1 x / 3 yrs
5 – 1 x / 5 yrs
6 – 1 x / 7 yrs
7 – ≤ 1 x / 8 yrs
8 – Don't Know
9 – Never
0 – Not Rated

Culvert Repairs Frequency ....CLVRTREP

The frequency that culvert repairs occur on the segment. Values collected were:

1 – ≥ 2 x / year
2 – 1 x / year
3 – 1 x / 2 yrs
4 – 1 x / 3 yrs
5 – 1 x / 5 yrs
6 – 1 x / 7 yrs
7 – ≤ 1 x / 8 yrs
8 – Don't Know
9 – Never
0 – Not Rated

Snow Plowing Frequency .... PLOWFREQ

The frequency that snow plowing occurs on the segment. Values collected were:

1 – Often, ≥ 5 x / yr
2 – Sometimes, 2 – 4 x / yr
3 – Rarely, ≤ 1 x / yr
4 – Never
5 – Don't Know
0 – Not Rated

Comments .... COMMENTS

General comments that the maintainers have about a given segment.

A.3 RELATED PUBLISHED ARTICLES

This appendix contains three refereed articles stemming from this project:

A.3.1 Huntington and Ksaibati, *Gravel Roads Asset Management*, Transportation Research Circular Number E–C078, Transportation Research Board of the National Academies, Washington, D.C., 2005.

A.3.2 Weaver, Huntington and Ksaibati, *Performance and Evaluation of Gravel Roads,* Transportation Research Record and TRB 85th Annual Meeting Compendium of Papers CD–ROM paper number 06–2487, Transportation Research Board of the National Academies, Washington, D.C., 2006.

A.3.3 Huntington and Ksaibati, *Gravel Roads Surface Performance Modeling,* Transportation Research Record and TRB 86th Annual Meeting Compendium of Papers CD–ROM paper number 07–0945, Transportation Research Board of the National Academies, Washington, D.C., 2007.

Gravel Roads Asset Management

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ABSTRACT

In the winter of 2004, the Wyoming Technology Transfer Center, in cooperation with the Wyoming Department of Transportation and Sheridan, Johnson, and Carbon counties of Wyoming, undertook a three-year project to institute a geographic information system (GIS) based asset management program. It encompasses inventorying, rating, and optimization strategies for improved gravel roads, as well as for the limited mileage of asphalt and unimproved roads in the counties. The roughly 2,000 miles of roads in the three counties were located with a global positioning system and rated using the Wisconsin Transportation Information Center's *PASER* manuals, modified for Wyoming's conditions. In addition, expenditures on each road section are tracked through maintainers' daily reports. Signs, sign supports, cattleguards, approaches, and culverts were rated and located. Bridges were located. Interviews with maintainers were conducted to gather historical and routine maintenance information on each section. This report describes the current status of this asset management program and road surface management system.

The goals of this program are two–fold, similar to those in widespread use for asphalt and concrete roads. First, it is to be used on a network level for financial and management decisions and strategies. Second, at the project level, it is to be used to make specific maintenance and construction recommendations on individual roads, largely through a life–cycle costing approach.

Off–the–shelf GIS software is used to enter and manipulate the data collected. Adapting this software to surface management tasks was relatively simple, given the user–friendliness of the newer GIS packages. Recent modifications allow for multiple entries for a single feature. Cost estimates for routine activities, such as mowing, snowplowing, and reshaping gravel roads, allow the counties to make reasonable, detailed estimates of the cost of maintaining gravel roads under different conditions. For these and numerous other applications, the asset management system is streamlining county operations.

The Wyoming Technology Transfer Center (T^2), part of the Local Technical Assistance Program (LTAP), has instituted an asset management program for three Wyoming counties: Carbon, Sheridan, and Johnson. They were chosen because they have had a recent, substantial increase in heavy truck traffic associated with oil and gas drilling. The goals of this project are two-fold: first, T^2 is quantifying the damages caused by the influx of heavy trucks; second, T^2 is designing and building a management system that can be taken over by the counties at the conclusion of the three year project.

The primary element in the asset management program is the road surface management portion. Many agencies have developed and instituted surface management systems, but most of these are primarily tailored to asphalt and concrete pavement surfaces. Less work has been done for gravel roads. The asset management system that comes out of this project should help fill this need.

As off–the–shelf geographic information system (GIS) software becomes more user friendly, it becomes easier for small municipalities to develop and maintain their own asset management systems. In spite of these advantages, setting up an asset management system is still beyond the capabilities of many agencies. For small Wyoming counties to reap the benefits of asset management, some other organization needed to step in and develop a management system tailored to their needs. The Wyoming T^2 Center has stepped into this role.

BACKGROUND

Asset Management

"Asset management is concerned with the entire life cycle of transportation decisions, including planning, programming, construction, maintenance, and operations. It emphasizes integration across these functions, reinforcing the fact that actions taken across this life cycle are interrelated. It also recognizes that investments in transportation assets must be made considering a broad set of objectives, including physical preservation, congestion relief, safety, security, economic productivity, and environmental stewardship." [1]

While state highway agencies, federal agencies, and most larger municipalities have already instituted asset and road surface management systems, such systems are less common among smaller municipalities. With the mandated GASB 34 standards, small municipalities have been compelled to establish the economic value of their road and street networks. However, complying with these functions merely provides the agencies with an inventory and a dollar figure. Generally, there are no technical or analytical capabilities associated with these inventories. Some organizations, including the Utah Technology Transfer Center and the Michigan Local Technical Assistance Program, have instituted asset management systems for municipalities in their states. Smaller municipalities have smaller infrastructures and correspondingly smaller budgets. Since computers can easily handle large amounts of data, there is a substantial economy of scale for larger agencies and a corresponding diseconomy of scale for smaller agencies.

Drilling Effects on Wyoming County Roads

A primary objective of this project is to quantify the damage being done to county roads by oil and gas drilling activities. Eastern Johnson and Sheridan counties and Western Carbon County have seen substantial increases in oil and gas drilling activities over the past few years. Roads that used to have light residential traffic and occasional heavy agricultural trucks now have numerous light and heavy trucks involved in drilling activities in addition to the traffic already present.

Road Rating Systems

There are a number of systems for evaluating road surface conditions. They range from labor intensive systems, such as the pavement condition index (PCI) to less labor intensive systems, such as the pavement surface evaluation and ratings (PASER) system developed by the Wisconsin Transportation Information Center. While the PCI involves detailed measurements of surface defects, the PASER system is a subjective, visual rating system designed for use by local officials. [2]

Gravel Roads

Deterioration of asphalt and concrete roads can be predicted based on initial construction and design, along with environmental effects, particularly traffic. Maintenance and repair of these roads is carried out every few years or so. The case is very different for gravel roads. Whenever moisture conditions are right, Wyoming county road and bridge crews are busy reshaping crowns, removing corrugations (washboards), and otherwise maintaining the gravel road surface. Low initial gravel road construction costs are at least partly offset by more frequent maintenance. Because of this fundamental difference between gravel and more durable pavement surfaces, it is essential that maintenance be considered in any analysis of gravel roads. To this end, the Wyoming T^2 Center is incorporating maintenance costs into its asset management system for gravel roads.

THE ASSET MANAGEMENT SYSTEM

Fundamentally, the asset management system begins with a global positioning system (GPS) receiver connected to a laptop computer. In the future, handheld computers with GPS technology may be used. GIS software puts information gathered by data collectors into the database and associates it with the locations established by the GPS receiver. Digital photographs are taken at each location to complement the measurements and evaluations. Maintenance data are collected by the county road and bridge crews that will allow the combination of maintenance costs and road condition data. In addition, the software allows for the inclusion of traffic data. The combination of these data provides the potential for performing powerful analyses of the county road networks.

Hardware and Software

Data were collected with a GPS unit and a laptop computer as shown in Figure 1. The ESRI product, ArcPad, was the front end for the graphical user interface (GUI). When the data collectors identified an asset, such as a one-mile road segment or a sign, the GPS was activated and the geographic data from the GPS were stored. Data entry forms were developed in ArcPad with scroll lists and comment fields, as shown in Figures 2 and 3. This made data entry both easier and reduced the likelihood of invalid or erroneous entries.

Data are downloaded daily using VPN Client software to transfer the data to the University of Wyoming's server housing the asset management data. This allows verification that the data are being collected and stored correctly. Since most of the data collectors have easy access to dial–up internet connections only, photographs are not transferred daily. Instead, they are saved on a CD that is sent to the T^2 center once a week.

The first year's database did not have a temporal component. Only one rating could be stored for a single road segment or feature. The database was restructured before the second year of data collection with two components, temporal and non–temporal data, functioning as a one-to-many relationship. For all rated segments and features there are multiple records describing what has happened to them. Queries can be written to describe the features as they vary with time.

To maintain the new GIS data set, it was migrated to a Geodatabase, which organizes data with the ArcGIS 9.0 software. Data are collected in shapefiles, a format supported by the software, then imported into the Geodatabase.

The new database allows additional data to be stored whenever a feature is reevaluated. A feature's location can be updated with the GPS as non–temporal data. When additional evaluations are conducted, a new record is added to the temporal data set. This relationship can exist since a common identifier is present in both the temporal and non–temporal databases. Unique identifiers serve as the link between a feature and its records collected at different times. The times are recorded in the temporal dataset along with the data entered at that time. This will allow for analysis of various features' changes over time, individually or collectively.

Hiring and Training

Teams of two students and retirees from various disciplines were hired. While data collection could be performed by one person, it was decided that in the interests of both safety and data accuracy it was best to have two people collect the data. Data collectors were trained at two-day training sessions conducted at the T^2 Center. They were given a short introduction to the engineering behind gravel and asphalt roads. The various distresses to be rated were described in detail. This was followed by numerous photographs, which were rated in the classroom by the data collectors as guided by an experienced engineer.

Surface Condition Data Collection

Data are collected in two passes. On the first pass, the road surface condition is evaluated in segments roughly one-mile long. The segments were established during the first year of data collection. These segments will be rated but not remapped in subsequent years. On the second pass, bridges are located and inventoried while the following features are located and evaluated: approaches, culverts, cattleguards, signs, and sign supports. This approach was taken for two reasons. First, it is easier to get the software to collect only lines or only points at a given time. Second, and most important, it would be very difficult to accurately evaluate the surface condition of a one-mile segment if the data collectors had to stop numerous times within the mile to rate and evaluate other features. It is difficult enough to get consistent surface ratings for a one-mile segment. If as long as an hour is spent rating other features within that segment, the quality of road surface data would be diminished.

Surface condition ratings are loosely based on the PASER systems with modifications deemed appropriate for conditions in Wyoming. All road surfaces were measured for top width and crown slope. The top width was measured from the edge of the traveled way and the shoulder. Crown slope was measured at a representative location with a four-foot level. The particular distresses rated for gravel and asphalt road surfaces are listed in Table 1. Gravel road overall conditions are rated as excellent, good, fair, poor, and failed. Asphalt roads overall conditions were rated as in the PASER rating system with 1 = failed, 2 = very poor, 3 = poor, 4 = fair, 5 = fair, 6 = good, 7 = good, 8 = very good, 9 = excellent, and 10 = excellent. Drainage on asphalt roads was rated on the same scale as that used for gravel roads. All other asphalt distresses were rated as none, low, medium, and high severity. Distresses not rated were assigned a 0.

One change from the first year, 2004, to the second year, 2005, was the splitting of Gravel Layer into two separate ratings: Gravel Quality and Gravel Sufficiency. Clearly these are two distinct issues. The question of whether they can be successfully evaluated is as yet unanswered.

Approaches, cattleguards, culverts, signs, and sign supports were evaluated for the characteristics listed in Table 2. Bridges were located and photographed only since WYDOT evaluates them.

Road Drainage in Wyoming and Wisconsin

One significant difference between the Wisconsin–developed PASER rating system and the Wyoming system is in how drainage is evaluated. Wyoming's precipitation patterns are different from those in more humid regions such as Wisconsin. During Wyoming winters, the ground is frozen and sometimes snowcovered. Spring thaws are relatively brief. Spring and summer rains tend to be brief and intense, followed by extended periods of warm, dry weather. The upshot of this is that bases and subgrades are less vulnerable to moisture since the time interval between frozen ground and sub–saturation moisture contents is relatively brief. However, frequent, intense rainstorms often lead to flash flooding. Wyoming soils don't absorb moisture as quickly as those in other parts of the country. Thus, drainage on Wyoming roads must be able to remove water quickly to prevent washouts, as shown in Figure 4. Though there are many roads in Wyoming that cross low lying, frequently saturated subgrades, most are well above the water table most of the time. An additional consideration is that most county roads are on the plains and prairies rather than through the wetter mountainous areas of the state; these are usually maintained by the United States Forest Service. In summary, with lower water tables, drainage on Wyoming county roads is designed as much to handle flash floods as it is to prevent base and subgrade saturation.

Traffic

The asset management system is set up to accommodate traffic data. As this data becomes available it will be added to the GIS–based asset management system database. There is also a field that will allow the designation of roads being used to service drilling operations. This will allow analyses to be performed assessing the effects of drilling traffic on these county roads.

Maintainers' Daily Reports

Data from the county road and bridge crews are being incorporated into the overall asset management program. Currently, each county has its own system for tracking the daily activities of their employees. The T^2 Center is developing a system for tracking maintenance expenses that will provide valuable information about the true costs of maintaining county roads. In the meantime, summary reports from the counties are being incorporated into the overall system.

Maintainers' Information

All three counties handle their road networks similarly. Each motor grader operator is responsible for about 100 miles of gravel roads. The T^2 Center attempted to gather information now stored in the maintainers' heads and put it into the database. The maintainers were asked questions such as: How many heavy trucks travel the road? Where was the gravel imported from? How often is the surface reshaped? Their reluctance to provide what might be inaccurate information limited the success of this approach. Alternate methods of getting this information will be tried in the future.

Quality Control

Quality control during the first year of data collection was performed by having an experienced engineer evaluate segments previously rated by the data collection teams. This evaluation was performed a few days or weeks after the initial data collection. The results of these evaluations are presented in Figure 5. Immediately after the quality control ratings were performed, the engineer and the data collectors got together to discuss discrepancies. In a few instances, discrepancies were attributed to washouts caused by recent rains or by recent maintenance. These conditions were easily identified in the photographs and were removed from the data used to generate Figure 5.

Figure 5 shows that the engineer generally rated the roads lower than the data collection teams. Though this was in part due to deteriorating road conditions during the time interval between when the data collectors rated the road and when the engineer rated the road, this probably does not account for all the discrepancies. At the post–quality control meetings these issues were addressed and adjustments were made.

For the second year of data collection, a different approach will be used. An engineer and a graduate student who performed data collection on the project last year will be the quality control personnel. After both the quality control personnel and the data collection team rate each segment they will get together and compare ratings. This should help assure that all data collection teams are rating the roads the same way since they will all conform to the views of the quality control personnel.

RESULTS

In 2004, nearly all the roads in the three counties were evaluated for their road surface conditions. Only a few roads in Sheridan County were not rated since they weren't passable in the data collector's passenger car. In Sheridan and Johnson counties, about a third of the other features were rated. Very few were rated in Carbon County because the Carbon County crew interviewed maintainers after they completed their road surface ratings rather than collect data on the other features. Table 3 shows the miles of gravel and asphalt roads rated in each county in 2004 and the number of features rated.

Insights can be gained about the road networks in the various counties. For example, Figure 6 shows the top widths by percentage for each county. While Carbon and Sheridan counties' gravel roads average 15-feet wide, Johnson County roads average 20-feet wide. Figure 7 shows the overall gravel roads conditions in 2004. In all counties, the majority of roads were rated good overall. In Johnson County there is a higher percentage of roads rated fair. As improved quality control and training procedures are implemented, the validity of this data will be assessed. Data from 2005 should indicate whether these differences are truly due to differing road conditions or to small differences in the rating standards of the data collection teams.

Another example, found in Figure 10, shows the drainage ratings for gravel roads in the three counties. Johnson County's drainage ratings are considerably higher than for the other two counties. This observation, combined with the wider top widths found in Johnson County, as shown in Figure 9, demonstrate that the geometries of Johnson County roads are generally better than in the other two counties. However, this is not reflected in the overall condition ratings. This discrepancy may be due to the use of lower quality gravel in Johnson County, a conclusion that is supported by subjective assessments of the overall condition of gravel roads in the three counties. This year's ratings of gravel quality should bear out this conclusion.

OUTPUTS

While the output phase of the asset management system is still in its infancy, some products have already been delivered to the counties. Ratings of the overall road conditions, such as the ones in Figure 9 for Carbon County, are in the hands of county commissioners and on the walls of county road and bridge shops. A map of blading costs on Sheridan County roads has been developed, as shown in Figure 10. Figures 11 and 12 show the relative ratings of potholes and washboards for the three counties. Comparisons of the various distresses observed in each county provide insights into the strengths and weaknesses of each county's road system. Queries have been written that answer such basic questions as: Where are the culverts that need to be cleaned? Where are the stop signs that are in poor or failed condition and what size are they? These simple reports are now providing useful information to the counties.

Future reports will contain information on more sophisticated analyses as well as more detailed reports of use to the counties. One fundamental question of interest to the counties is how far is it worth hauling high quality gravel? Combining materials and hauling costs of lower and higher quality gravel with the maintenance costs associated with these gravels should allow analyses to be performed that optimize the use of available materials. This issue is particularly well defined in Sheridan and Johnson counties where high quality aggregate is available in the western parts of the counties in the foothills of the Bighorn Mountains. The eastern part of these counties, where much of the drilling activity is taking place, has little high quality aggregate. The question becomes at what point is it cost effective to spend more money up front on good gravel, thereby reducing long-term maintenance costs? The database will be populated with maintenance cost data, road condition data, and traffic data. Answers to questions such as these will be sought.

CONCLUSIONS

Though this project has been ongoing for just over a year, great strides have been made toward developing a functional asset management system that will provide Wyoming counties with vital information on the status of their road networks. In the long term, some crucial decisions need to be made: Who will maintain the database? Who will collect and update condition data? What reports will be generated?

Other issues are being addressed. Splitting the gravel layer rating into two parts, gravel sufficiency and gravel quality, provides more information to the counties about how they might address some of their gravel roads' performance issues. Johnson County is addressing some of their culvert placement problems. Culvert inlets and outlets should be flush with the bottom of the ditch and the foreslope. This is not always the case. Procedures are being developed that will provide the counties with data assessing this issue, perhaps defining critical measurements and taking photographs that portray the existing culvert placement. These and other arising issues can be handled by making relatively simple additions to the database and forms, along with additional training for the data collectors.

By working together with the counties, the T^2 Center has developed a system that will provide valuable information to these three counties, as well as a blueprint for other similar agencies. As the needs of the counties become better defined, the flexible nature of the asset management system allows it to adapt to new situations and concerns.

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Disclaimer
The mention of specific commercial products is for informational purposes only and does not constitute an endorsement by the Wyoming Technology Transfer Center, the Wyoming Department of Transportation, the University of Wyoming, or Sheridan, Johnson, or Carbon counties.

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PERFORMANCE AND EVALUATION OF GRAVEL ROADS

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ABSTRACT

The Wyoming Technology Transfer Center has undertaken a study that evaluates and predicts deterioration of gravel roads. Twenty 1,000-ft. gravel road sections on Wyoming county roads have been visually rated and measured on a weekly basis. Gradation and plasticity of the road surfacing, base, and subgrade have been evaluated in the laboratory.

Most of the information about gravel roads' performance is qualitative, based on the judgment of experts: This paper adds to the quantitative knowledge by assigning numeric values to various performance measures and analyzing these measures as a function of time and other factors.

Fifteen independent variables describing the gravel road sections' traffic, surfacing aggregate, subgrade materials, and drainage are used to predict the rate at which the dependent variables, overall condition, potholes, rutting, and washboards deteriorate. P–values are used to evaluate each individual independent variable's effect on each of the dependent variables. Using these variables, relatively simple equations describing surface deterioration achieved R^2 values of 31% for overall condition, 62% for potholes, 58% for rutting, and 19% for washboards. The overall condition's deterioration rate is predicted by heavy truck traffic (ESAL), median speed, and crown slope; pothole and rut formation are predicted by heavy truck traffic and surfacing thickness, and washboarding by the 85^{th} percentile speed and the coarse sand fraction.

KEYWORDS

Gravel, performance, deterioration, unpaved, drainage, surfacing, aggregate, traffic, PASER

INTRODUCTION

The Wyoming Technology Transfer Center (T^2) is developing an asset management program for three Wyoming counties. One of the system's goals is to predict the effects of various funding levels and maintenance strategies on the counties' road networks. These three counties combined have about 2,000 miles (3,200 km) of roads. About 1,800 miles (2,900 km) are unpaved. In order to predict road network conditions, some basis for projecting deterioration of unpaved roads is needed.

Considerable research has been completed, evaluating materials used for unpaved road construction, particularly for dust control problems. In addition, there have been many studies examining deterioration rates of asphalt and concrete pavements. However, minimal work has been performed evaluating gravel roads' deterioration rates. This paper contains information about gravel roads' deterioration rates, along with some preliminary assessments of the factors contributing to this deterioration.

BACKGROUND

"At the present time 50% of the mileage of surfaced roads in the United States are gravel roads. They are suitable for volumes of traffic up to 350 to 400 vehicles daily. Beyond this limit they often become rough on account of so–called rhythmic corrugations which are difficult to control." (*1*) Since that was written in 1927, those responsible for maintaining gravel roads are still battling the same problem. Corrugation, often referred to as washboarding, is still a major problem though progress is being made by refining aggregate characteristics and adding soil stabilization products and dust suppressants to surfacing gravel. Nowadays "Too often surface gravel is taken from stockpiles that have actually been produced for other uses." (*2*) Clearly, there is plenty of room for improvement in how unpaved roads are constructed and maintained.

As the research community puts a heavy emphasis on asphalt and concrete roads, gravel roads are receiving less attention. Some of the methodology used for higher volume roadways, such as those found in a recent NCHRP report, *Optimal Timing of Pavement Preventive Maintenance Treatment Applications* (*3*), could also be applied to gravel roads.

OBJECTIVE

The primary objective of this study is to obtain performance information about gravel roads' deterioration rates. This information can be used to take management and maintenance principles now used for paved roads and apply them to unpaved roads. Like the higher service roads, gravel roads' conditions deteriorate, though the time frame is generally shorter. Various road maintenance activities are appropriate at different times. Actions on gravel roads, such as reshaping the crown, adding dust suppressants, and adding new gravel, can be considered analogous to activities such as crack sealing, chip sealing, and overlays. While much data are available for asphalt and concrete roads from sources such as the Long–Term Pavement Performance Program (LTPP), similar data for gravel roads are scarce. This study helps fill that void.

DATA COLLECTION

The general objective of this study is to provide tools that will allow prediction of gravel roads' deterioration, at least in Wyoming's dry–freeze climate. Twenty 1,000-ft (300-m) study sections were selected. Each section was divided into two subsections, one to receive routine maintenance, as performed by the county road and bridge crews, while the other was to be left unmaintained until safety considerations dictated otherwise. These sections were evaluated on a weekly basis.

Site Selection

The test sections were selected by county road and bridge supervisors in consultation with T^2 personnel. They were selected to provide a variety of both traffic volumes and traffic types. The selected roads are generally well maintained; since this study began in May, the roads were all recently bladed since spring rains allowed the crews to maintain the roads while they were damp. Figure 1 shows the locations of the test sections. All three counties have experienced significant impacts from both new residences and oil and gas drilling, like many parts of Wyoming.

Site Evaluations

The research team collected data on over 20 variables, which are listed in Table 1. Road conditions and measurements were assessed on a weekly basis beginning in May 2005 with ratings conducted through August 2005. The laboratory data are based on samples collected in January 2005.

TABLE 1. Road Condition, Traffic, and Laboratory Variables Included in This Study

Laboratory Data	Road Measurements	Condition Ratings	Traffic Data
Aggregate Gradation	Top Width	Overall Condition	Median Traffic Speed
Liquid Limit	Crown Slope	Potholes	85th Percentile Speed
Plastic Limit	Float/Drag–off Test	Washboards	Average Vehicles per Day
Fractured Faces	Thickness[a]	Rutting	Average ESALs[b] per Day
		Dust	
		Loose Aggregate	
		Gravel Quality	
		Gravel Sufficiency	
		Crown Shape	
		Drainage	

[a] Thicknesses of the surfacing and base gravels were measured during sampling for the laboratory tests.
[b] One ESAL is one equivalent single 18,000-lb (8,165-kg) axle load based on FHWA Classes for asphalt pavements.

Laboratory Evaluations

Samples of the surfacing gravel, base gravel, and subgrade were tested for coarse aggregate fractured faces, gradation, liquid limit, and plastic limit. Plasticity indexes, coarse sand fractions, fine sand fractions, fines fraction, and soil classifications were generated using the test results. Two samples were taken at each test section. The results of these tests are presented in Table 2 for surfacing materials and in Table 3 for subgrade materials. During sampling, thicknesses were measured. Thicknesses are presented in Table 4.

Though most of the gravel does not have additives, some contain reclaimed asphalt pavement (RAP). The presence of RAP was noted during testing.

Sampling and Thicknesses

Thickness measurements and sampling in Carbon County were carried out with an electric hammer. This was a difficult and time consuming process since the ground was frozen. Due to the difficulty of getting deep into the road structure, subgrade samples were taken from adjacent soils. Efforts were made to get samples that would be representative of the subgrade materials under the road surface.

Sampling in Johnson and Sheridan Counties was conducted with a 6-in. (0.15-m) electric auger. This more effective method allowed subgrade samples to be taken from directly under the road.

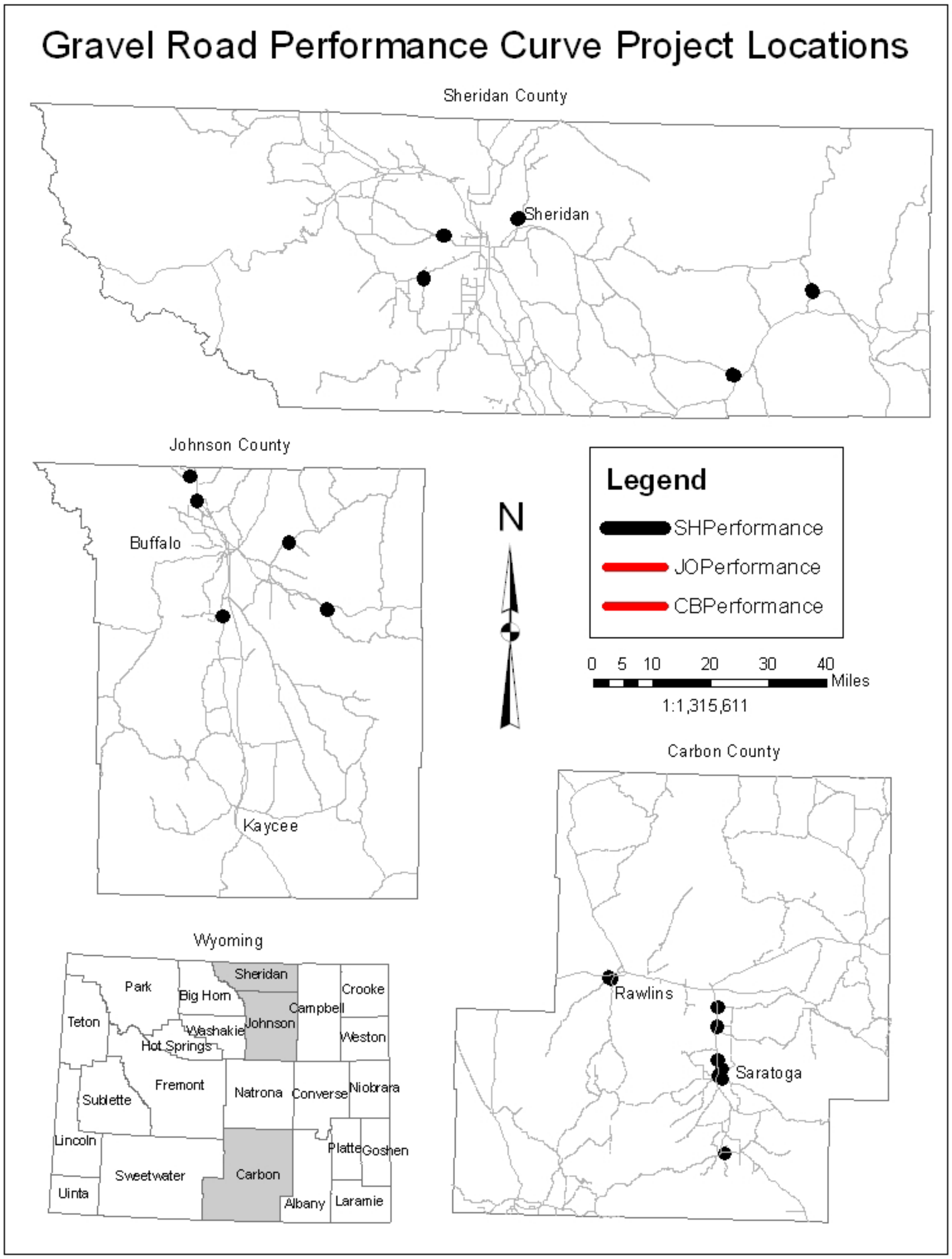


FIGURE 1. Test section locations

Gradation

The aggregate gradation was determined by sieve analysis according to AASHTO T 27 "Sieve Analysis of Coarse and Fine Aggregate," and wash analyses were performed according to AASHTO T 11 "Materials Finer Than 75–µm (No. 200) Sieve in Mineral Aggregates by Washing." Some aggregates were not washed and only evaluated using T 27 due to the presence of RAP.

Liquid Limit, Plastic Limit, and Plasticity Index (PI)

The Liquid Limit was determined according to AASHTO T 89 "Determining the Liquid Limit of Soils." The plastic limit and plasticity index were determined according to AASHTO T 90 "Determining the Plastic Limit and Plasticity Index of Soils."

Fractured Faces

Samples of the material passing a ⅜-in. (9.5-mm) sieve and retained on a #4 (4.75-mm) sieve were evaluated as were samples of material retained on a ⅜ in. (9.5-mm) sieve. Those particles in the sample with two or more fractured faces were separated and they were weighed, yielding a percentage of the coarse material with fractured faces.

Soil and Aggregate Classification

Using the gradation and plasticity data, the soils were categorized using AASHTO M 145 "Classification of Soils and Soil–Aggregate Mixtures for Highway Construction Purposes."

Road Measurements

Several measurements are made on the test sections each time the road is rated. They are described below. In addition, thicknesses were measured during sampling for the laboratory testing, also as described below. The results of these measurements are presented in Table 4.

Top Width

The top width is measured from the hinge of the shoulder and roadway surface as described in the South Dakota LTAP Manual (*2*). Sometimes this hinge is rounded or covered with vegetation, making exact measurements difficult. For this reason, top widths are measured only to the nearest foot (0.3 m).

Crown Slope

The crown slope was measured using a 4-ft. (1.22-m) level. For a gravel road, the ideal cross slope is ½-in. per foot, about 4% (*2*). The level is placed on the road surface in a location that visually appears to represent the section as a whole. The elevation difference over the length of the level is measured and recorded to the nearest quarter inch. This is then converted to a slope in percent. On roads with significant rutting, this measurement can become rather difficult. As for the top width, there is a degree of subjectivity in the crown measurements, largely due to the selection of the spot where the measurement is made.

Float (Drag–off) Test

Float tests, sometimes referred to as drag-off tests, were performed each time a test section was evaluated. A flat 0.75-ft. (0.23-m) wide shovel was used to pick up all easily removed aggregate from the top width of the road, one shovel width wide. This material was weighed. The top width in feet was multiplied by the shovel width, 0.75-ft., to determine the loose aggregate per square yard.

Thickness

Visual examination of the materials during sampling generally allowed the road structure to be split into surfacing gravel, base gravel, and subgrade material, though this method is less accurate than for other road surfaces. Each material was sampled and each layer's thickness was recorded.

TABLE 2. Surfacing Materials Properties

Road Name	Sub–section	PI	Soil Type[a]	Coarse Sands, %[b]	Fine Sands, %[c]	Fines, %[d]	Fractured Faces, %[e]
Ferris (South)	A	NP	A–4	9	49	39	77
	B	9	A–2–4	17	41	34	100
Ferris (North)	A	12	A–2–6	26	25	22	99
	B	14	A–6	15	32	36	94
Twenty Mile	A	17	A–2–6	12	29	35	97
	B	17	A–6	8	24	54	100
Rattlesnake Pass	A	NP	A–2–4	16	14	33	—
	B	NP	A–2–4	15	14	31	—
Pass Creek	A	NP	A–2–4	28	24	3	—
	B	8	A–2–4	20	43	23	88
Fish Hatchery	A	NP	A–2–4	11	66	19	95
	B	NP	A–2–4	20	55	15	83
Mountain View	A	NP	A–1–b	20	34	14	61
	B	NP	A–2–4	17	45	21	94
Leavengood	A	13	A–2–6	13	18	13	25
	B	8	A–2–4	19	27	14	18
Lake Creek	A	NP	A–2–4	21	43	18	86
	B	11	A–2–6	36	27	13	85
Black Hall	A	6	A–2–4	31	34	26	97
	B	NP	A–1–b	28	25	17	75
Crazy Woman	A	14	A–2–6	18	24	27	42
	B	NP	A–1–b	18	22	17	61
Tipperary	A	NP	A–1–b	30	23	12	80
	B	NP	A–1–b	21	28	18	81
Schoonover	A	NP	A–1–b	30	26	13	68
	B	NP	A–1–b	33	24	11	62
Shell Creek	A	NP	A–1–b	20	27	13	62
	B	NP	A–1–b	21	23	12	53
Wagonbox	A	NP	A–1–a	24	17	13	78
	B	NP	A–1–b	23	22	14	86
Ulm	A	NP	A–1–b	29	30	14	76
	B	NP	A–1–b	31	30	16	76
Passaic	A	NP	A–1–b	29	33	15	91
	B	NP	A–1–b	33	32	10	90
Beaver Creek	A	NP	A–1–b	22	17	17	82
	B	NP	A–1–b	25	19	17	83
Soldier Creek	A	NP	A–1–b	20	21	18	54
	B	NP	A–1–a	26	20	13	79
Lower Prairie Dog	A	NP	A–1–a	40	25	6	71
	B	NP	A–1–b	34	24	13	—

[a] AASHTO soil classification
[b] Percentage passing a #4 (4.75 mm) sieve and retained on a #30 (600 µm) sieve
[c] Percentage passing a #30 (600 µm) sieve and retained on a #200 (75 µm) sieve
[d] Percentage passing a #200 (75 µm) sieve
[e] Percentage retained on a #4 (4.75 mm) sieve having two or more fractured faces
— Not available

TABLE 3. Subgrade Materials Properties

Road Name	Sub–section	PI	Soil Type[a]	Coarse Sands, %[b]	Fine Sands, %[c]	Fines, %[d]
Ferris (South)	A	NP	A–2–4	22	37	25
	B	9	A–4	9	48	39
Ferris (North)	A	15	A–6	10	40	37
	B	NP	A–2–4	14	53	21
Twenty Mile	A	10	A–2–4	11	55	26
	B	10	A–4	2	38	58
Rattlesnake Pass	A	NP	A–2–4	3	83	13
	B	NP	A–2–4	5	78	15
Pass Creek	A	10	A–2–4	13	56	20
	B	NP	A–2–4	9	56	28
Fish Hatchery	A	NP	A–2–4	9	69	20
	B	NP	A–2–4	7	77	14
Mountain View	A	NP	A–2–4	13	44	25
	B	NP	A–2–4	11	54	31
Leavengood	A	NP	A–4	4	44	48
	B	NP	A–4	3	41	56
Lake Creek	A	NP	A–2–4	10	58	15
	B	NP	A–2–4	8	63	21
Black Hall	A	NP	A–2–4	23	39	24
	B	NP	A–1–b	21	31	22
Crazy Woman	A	20	A–6	7	33	57
	B	23	A–6	9	26	51
Tipperary	A	15	A–6	16	21	50
	B	15	A–6	5	29	62
Schoonover	A	27	A–7–6	5	22	65
	B	28	A–7–6	4	18	74
Shell Creek	A	NP	A–2–4	17	44	35
	B	NP	A–2–4	20	44	32
Wagonbox	A	14	A–2–6	21	32	33
	B	19	A–6	14	40	39
Ulm	A	14	A–6	17	31	41
	B	NP	A–2–4	11	48	32
Passaic	A	22	A–6	9	31	48
	B	12	A–6	8	53	37
Beaver Creek	A	—	—	—	—	—
	B	—	—	—	—	—
Soldier Creek	A	25	A–7–6	10	16	59
	B	—	—	—	—	—
Lower Prairie Dog	A	24	A–6	18	22	46
	B	30	A–7–6	16	23	48

[a] AASHTO soil classification
[b] Percentage passing a #4 (4.75 mm) sieve and retained on a #30 (600 µm) sieve
[c] Percentage passing a #30 (600 µm) sieve and retained on a #200 (75 µm) sieve
[d] Percentage passing a #200 (75 µm) sieve
[e] Percentage retained on a #4 (4.75 mm) sieve having two or more fractured faces
— Not available

TABLE 4 Site Measurements

Road Name	End	Top Width, ft	Average Float, lb/sy	Average Crown	Geometry[a]	Thickness, in Surface	Thickness, in Gravel
Ferris (South)	A	22	8	3.8%	F, T	4	9
	B	23	9	4.2%	F, T	4	12
Ferris (North)	A	21	2	2.9%	F, T	4	11
	B	22	2	3.9%	F, T	5	10
Twenty Mile	A	22	5	2.8%	F, T	3	8
	B	23	4	2.2%	F, T	3	10
Rattlesnake Pass	A	22	13	4.7%	F, T	4	10
	B	23	17	4.6%	F, T	3	10
Pass Creek	A	21	8	4.0%	F, T	6	12
	B	22	11	3.5%	F, T	4	11
Fish Hatchery	A	22	9	3.6%	F, T	4	12
	B	23	9	3.2%	F, T	4	12
Mountain View	A	23	5	3.2%	F, T	4	11
	B	22	4	2.5%	F, T	5	9
Leavengood	A	22	5	3.1%	F, T	5	14
	B	22	5	3.1%	F, T	8	14
Lake Creek	A	23	5	4.5%	F, T	6	14
	B	23	5	3.2%	F, C	5	11
Black Hall	A	28	1	3.2%	F, T	9	17
	B	28	2	3.0%	F, T	8	18
Crazy Woman	A	27	17	2.0%	F, T	7	7
	B	27	16	1.4%	F, T	7	7
Tipperary	A	25	26	3.4%	F, T	4	8
	B	25	15	3.4%	H, T	4	4
Schoonover	A	22	15	2.9%	F, T	3	3
	B	22	11	2.6%	F, T	7	7
Shell Creek	A	27	5	3.7%	F, T	5	5
	B	28	7	4.0%	F, C	5	5
Wagonbox	A	25	6	3.2%	F, T	5	5
	B	24	4	2.7%	H, T	5	5
Ulm	A	21	24	3.6%	F, T	8	8
	B	21	29	3.8%	F, T	12	12
Passaic	A	20	7	4.7%	F, T	2	2
	B	20	6	4.6%	F, T	3	3
Beaver Creek	A	24	6	4.3%	F, T	10	10
	B	23	9	4.3%	F, T	15	15
Soldier Creek	A	24	11	4.3%	F, T	7	7
	B	24	13	4.6%	F, T	2	2
Lower Prairie Dog	A	26	18	3.5%	F, T	15	15
	B	26	18	3.9%	F, T	11	11

a. T = tangent, F = flat, H = hill, C = curve

Road Conditions

Road rating standards were developed by the Wyoming T^2 Center as part of the asset management program, and used for this study as well. These standards are loosely based on the Wisconsin Transportation Information Center's *Gravel – PASER Manual* (*4*), as modified for Wyoming's drier climate. The average and standard deviation of the condition ratings by county are shown in Table 5. The PASER system allows roads to be rated by a visual inspection. Slide presentations prepared by the Wisconsin Transportation Information Center and the Wyoming T^2 Center used numerous photos to describe the various conditions. All rated characteristics, except the overall condition, are assigned a value from 2 to 10, with 10 = excellent, 8 = good, 6 = fair, 4 = poor, and 2 = failed. This system is the same as the one used in the PASER Manual (*4*), except that the numeric values are doubled so all ratings are on a one–to–ten scale.

Overall Condition Ratings

The overall road conditions were rated on a one–to–ten scale with 10 being excellent and 1 being failed. This is a departure from the PASER system, which rates gravel roads on a one–to–five scale. Based on previous experience rating gravel roads, the research team felt the more precise rating of a one–to–ten scale could be successfully undertaken, and that better results could be achieved using this more precise scale. The overall rating considers ride characteristics as well as rutting, washboards, potholes, dust, and loose aggregate, and ratings that should indicate long–term performance such as drainage, crown shape, gravel quality, and gravel sufficiency.

Potholes

Potholes, depressions in the road surface that can hold water and contribute to a rough ride, were rated. Sometimes the evaluator had to discriminate among depressions in the road that may be considered either washboards, ruts, or potholes. Depressions associated with the rhythmic pattern of washboards were not considered potholes, nor were deep areas within ruts. Such depressions were considered in the washboard or rutting ratings but not in the pothole ratings.

Washboards

Washboards, often referred to as corrugations, were rated with the value assigned being dependent on both the severity and sufficiency of these rhythmic undulations in the road surface.

Rutting

Ruts in the road were evaluated visually, with the rating being dependent on both the extent and severity of the ruts.

Dust

The amount of dust coming off the roads due to passing traffic was rated. Dust was not rated when there had been recent precipitation.

Loose Aggregate

The loose aggregate rating assesses the amount of loose aggregate on the road surface. While the float test described above measures the total loose material from shoulder to shoulder, the loose aggregate value rates the unbound material in windrows between the wheelpaths and any loose aggregate in the wheelpaths.

Gravel Quality

The quality of the gravel on the road surface was evaluated visually. The primary factors considered were gradation, plasticity, and fractured faces. A good blend of coarse and fine rock with lots of fractured faces was considered good gravel. The gravel's ability to form a good crust that drains water quickly was also considered. This subjective rating, combined with the laboratory test results, provides an overall picture of the material quality for each section.

Gravel Sufficiency

This rating is the evaluator's impression of whether there is sufficient gravel to carry the traffic for each section. One considers the overall structure, as well as surface performance, when making this rating. A well built up road without significant rutting or soft spots is considered to have good gravel sufficiency.

Crown Shape

The shape of the crown was rated visually, in addition to being measured as described below. While the measured crown slope assesses the magnitude of any crown, the crown shape rating assesses the overall shape, particularly highlighting those surfaces that are flat at the center even though they have good slope on the sides of the road.

Drainage

The overall quality of drainage for each road section is evaluated, ignoring the runoff from the top surface since this is considered in other rated factors, primarily the crown slope and crown shape and secondarily by the gravel quality and ruts. Height above the surrounding terrain, depth and shape of the ditches, and the effectiveness of culverts are considered when evaluating drainage.

TABLE 5. Condition Ratings by County

	Carbon		**Johnson**		**Sheridan**	
Condition	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
Overall	5.6	1.04	5.4	1.58	5.6	1.58
Potholes	7.6	1.35	7.4	1.80	7.9	1.41
Washboards	7.0	1.41	6.8	1.87	6.5	2.06
Rutting	8.1	0.61	8.2	0.87	8.0	0.73
Dust	8.3	1.14	7.8	1.35	7.9	1.45
Loose Aggregate	8.6	1.11	7.9	1.42	8.3	1.32
Gravel Quality	8.6	1.23	8.7	1.21	9.1	1.12
Gravel Sufficiency	9.6	0.84	10.0	0.26	9.7	0.68
Crown Shape	7.9	0.96	7.5	1.68	8.8	1.22
Drainage	9.4	1.03	9.9	0.44	9.3	1.02

Traffic Data

Traffic data were collected on all 20 sections using counters that provide raw data in the form of a time stamp each time an axle crosses the tube. The tubes are typical asphalt traffic counter tubes that detect pressure differences when a vehicle passes over them. The tubes are not durable enough to be left on gravel roads unprotected so they are placed inside canvas fire hoses. Two tubes were placed eight feet apart. This configuration allows for the collection of traffic volume, speed, and classification into Federal Highway Administration (FHWA) classes.

Traffic counts were performed for one week on each section. Since the sections have combinations of residential, recreational, drilling, and other types of traffic, it was considered important to get both weekday and weekend traffic data. The raw time stamp data obtained by the counter tubes were analyzed with software provided by the counter manufacturer. Daily traffic volumes, speeds, and classifications were all calculated from the raw data. Using the FHWA classifications and the 18,000-lb. (8,165-kg) equivalent single axle load (ESAL) coefficients used by the Wyoming Department of Transportation for asphalt roads, average daily ESAL were calculated. As shown in Table 6, the vehicles per day ranged from 50 to 694, while the ESAL per day ranged from 5 to 215.

TABLE 6 Test Sections: Traffic

County	Road Name	Median Vehicle Speed, mph	85^{th} Percentile Vehicle Speed, mph	Average Vehicles per Day	Average ESALs per Day
Johnson	Crazy Woman	26	35	198	29
Johnson	Tipperary	40	51	68	14
Johnson	Schoonover	28	41	230	75
Johnson	Shell Creek	32	42	138	27
Johnson	Wagonbox	23	32	278	22
Carbon	Ferris (South)	31	42	90	17
Carbon	Ferris (North)	19	27	210	42
Carbon	Twenty Mile	21	29	152	37
Carbon	Rattlesnake Pass	34	44	21	3
Carbon	Pass Creek	36	46	42	8
Carbon	Fish Hatchery	38	47	57	9
Carbon	Mountain View	26	34	53	5
Carbon	Leavengood	24	34	88	8
Carbon	Lake Creek	22	28	440	57
Carbon	Black Hall	28	34	338	44
Sheridan	Ulm	37	50	62	8
Sheridan	Passaic	38	54	98	20
Sheridan	Beaver Creek	36	43	524	63
Sheridan	Soldier Creek	42	49	303	35
Sheridan	Lower Prairie Dog	38	45	694	215

DATA ANALYSIS

The field ratings and measurements, laboratory test results, and traffic data were compiled into a computerized database. The deterioration rates of potholes, rutting, washboards, and overall condition expressed as rating points per day were generated as described below. Only summer data were used to establish these deterioration rates since fall, winter, and spring data are not yet available. Simple linear regressions were performed using the 15 independent variables listed in Table 7. The p–values, the probability that the relationship between the dependent and independent variables is random, are also presented in Table 7. Of the 60 combinations of independent and dependent variables, 21 had p–values less than 0.1, indicating that there is a 90% probability that the variation in the dependent variable's deterioration rate was due to changes in the independent variable. Regression analyses were performed that attempted to come up with simple predictors of the four dependent variables' deterioration rates.

TABLE 7 Individual Variable p–values

		Overall	**Potholes**	**Rutting**	**Washboards**
Traffic	**Median Speed**	0.0272	0.3651	0.4801	0.0390
	85th % Speed	0.0395	0.6864	0.9239	0.0332
	ADT	0.3467	0.0001	0.0001	0.9572
	ESAL/day	0.0547	0.0000	0.0000	0.3603
Thickness	**Gravel Thickness, inches**	0.6154	0.7895	0.3512	0.6119
	Surfacing Thickness, inches	0.1218	0.0128	0.1243	0.3730
Surfacing	**Coarse Sand: #4 – #30**	0.0429	0.0095	0.0503	0.0198
	Fine Sand: #30 – #200	0.5960	0.2719	0.8863	0.8432
	Fines: – #200	0.4750	0.1594	0.7406	0.2448
	PI	0.1491	0.3530	0.3528	0.0372
	>=2 Fractured Faces	0.3372	0.2240	0.6279	0.5775
Subgrade	**PI**	0.0354	0.0073	0.0916	0.1718
Drainage	**Crown Slope**	0.5811	0.4748	0.9351	0.5915
	Crown Shape	0.4865	0.2142	0.5727	0.7812
	Drainage	0.0836	0.0712	0.0284	0.1558

Deterioration Rates

Deterioration rates were generated from the temporal condition ratings. Regressions of condition ratings as a function of time were conducted; separate regressions were performed before and after maintenance and combined as a weighted average to get a single deterioration rate for each section. Regression analyses using time as the independent variable and condition as the dependent variable were performed, yielding deterioration rates in points per day. The points are based on a 10 scale, with 10 being excellent and one being failed. Thus, as the condition of a road gets worse, it has a negative deterioration rate.

In a few instances, positive deterioration rates were observed, implying that the condition improved between ratings. There are several possible ways this might occur: The evaluator may have simply rated similar conditions slightly differently, maintenance may have occurred but not been reported, or possibly the road actually improved. For the regression analyses, the positive deterioration rates were converted to deterioration rates of zero in hopes that the results of the statistical analyses would not be skewed by the positive deteriorating rates, thereby hiding effects that lead to gravel roads' deterioration.

Indexing of Plasticity Index (PI)

Since many soils are non–plastic, a numerical value had to be assigned to these non–plastic soils to perform statistical analyses. A value of zero was selected for the PI of non–plastic materials.

p–values

For each independent variable, p–values were established using that variable alone to predict each independent variable's deterioration rate as shown in Table 7. Interestingly, the only variable that affected all four dependent variables was the coarse sand fraction. The other surprise was the limited effects of gravel thicknesses. This may be attributed, at least in part, to the difficulty in establishing lift thicknesses – such measurements are not nearly as straightforward as for asphalt or concrete roads, particularly considering that many of the subgrades are high quality, sandy soils and much of the gravel is locally obtained, sometimes mixed on–site with the subgrade to assist cohesion. Another factor may be the correlation of thicknesses with traffic. The correlation between ADT and surfacing thickness is 0.64 while the correlation between ESAL/day and surfacing thickness is 0.57. Not surprisingly, truck traffic and subgrade PI affected all dependent variables except washboarding.

Overall Conditions

The overall rating is affected by six of the 15 independent variables. Traffic speed and truck traffic, though not vehicle counts, affect the overall condition. Surprisingly, the thickness was not shown to be a significant factor. Two materials properties, the coarse sand fraction and the subgrade PI, were significant. Finally, drainage was also statistically significant.

Potholes

Traffic speed did not affect the pothole formation rate, though traffic volumes did, both total vehicles and trucks. Surfacing thickness also affected potholing, as did the coarse sand fraction, subgrade PI, and drainage.

Rutting

Rutting, like potholing, is affected by traffic volumes but not speeds. Coarse sand fraction, subgrade PI, and drainage also affect rutting.

Washboards

As one would expect, traffic speed, surfacing PI, and coarse sand fraction are the only significant variables affecting washboarding.

Regression Coefficients

Table 8 contains the regression coefficients for independent variables with p–values less than 0.1 times the standard deviation of the variable, each analyzed for all four dependent variables with the independent variable as the only predictor of the dependent variable. This provides an indicator of the relative significance of each variable in predicting the particular condition. Negative coefficients indicate that as the independent variable in question increases, the deterioration rate also increases, since deterioration rates are expressed as negative values.

Overall Condition

All six independent variables affecting overall condition have similar values ranging from –0.0079 for drainage to –0.0102 for subgrade PI. Traffic speed, truck volume, coarse sand fraction, subgrade PI, and drainage all affect overall conditions. There is, however, one surprise: better drainage, as indicated by higher ratings, accelerated the overall deterioration rate. Perhaps this is because the data this study is based on data collected between the end of May and the end of August when very little moisture was present. Road drainage in Wyoming may only be useful in preventing flash flood damage and during the spring thaw, neither of which was evaluated in this study.

Potholes

The most significant factor affecting pothole formation is traffic volume, both total vehicles and trucks. Surfacing thickness, coarse sand fraction, subgrade PI, and drainage all have lesser effects. As described in the previous paragraph, the effects of drainage are opposite what one would expect.

Rutting

Rutting is affected largely by the same factors as potholes, though surfacing thickness does not seem to be a significant factor. As for potholes, traffic volume has the greatest effect, with materials properties and drainage having lesser effects.

Washboards

Washboard formation is not significantly affected by traffic volumes, though traffic speeds are significant. The only other factors affecting washboard formation rates are the coarse sand fraction and the surfacing aggregate’s PI.

TABLE 8. Regression Coefficients Times Standard Deviation for Variables with p–values Less Than 0.1

		Overall	Potholes	Rutting	Washboards
Traffic	**Median Speed**	–0.0100	—	—	–0.0122
	85th Percentile Speed	–0.0094	—	—	–0.0126
	ADT	—	–0.0162	–0.0097	—
	ESAL/Day	–0.0088	–0.0221	–0.0125	—
Thickness	**Gravel Thickness, inches**	—	—	—	—
	Surfacing Thickness, inches	—	–0.0109	—	—
Surfacing	**Coarse Sand: #4 – #30**	–0.0092	–0.0114	–0.0053	–0.0137
	Fine Sand: #30 – #200	—	—	—	—
	Fines: – #200	—	—	—	—
	PI	—	—	—	0.0124
	>=2 Fractured Faces	—	—	—	—
Subgrade	**PI**	–0.0102	–0.0125	–0.0049	—
Drainage	**Crown Slope**	—	—	—	—
	Crown Shape	—	—	—	—
	Drainage	–0.0079	–0.0081	–0.0059	—

— p–value is greater than 0.1

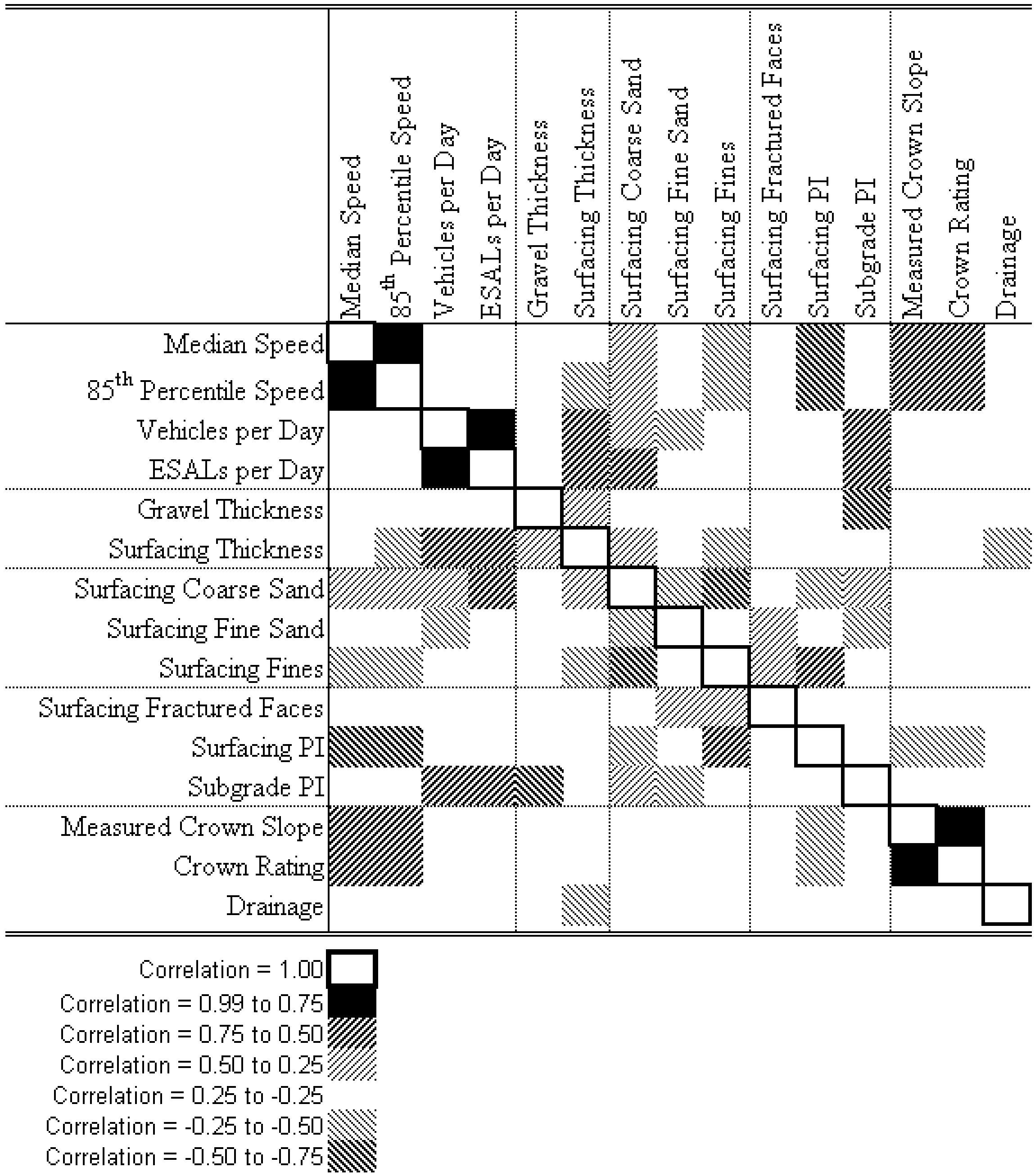
Note: Negative coefficients indicate that as the value of the variable increases, the road deteriorates faster.

Correlations

Independent Variables

To learn about our data, in particular about any pitfalls encountered during analysis, a correlation of all independent variables was performed, as shown in Table 9. Most of the stronger correlations are not surprising; measured crown and crown ratings are highly correlated. A few are not so obvious; surfacing PI and speeds are highly correlated – a problematic situation since both variables are believed to contribute significantly to washboarding. Another result that is also problematic and clearly coincidental is the high correlation between subgrade PI and traffic volume. When viewing the regression analyses that follow, one should consider these issues.

TABLE 9. Correlation Factors of Independent Variables



Stepwise Regression

Overall Condition

Both forward and backward stepwise regressions were performed on the overall condition, adding or removing variables until an equation was arrived at with all independent variables having p–values less than 0.1. Using this approach, the same five variables were selected with both methods to predict the overall condition with an R^2 value of 47%. The following equation predicts the overall condition deterioration rate:

$$O_{DR} = 0.0100 + S(–0.00234) + C(0.0218) + D(–0.0106) + T(–0.00281) + F(–0.000399)$$

Where: O_{DR} = Overall condition deterioration rate, Rating points per Day
S = Median Speed, mph
C = Crown Slope, %
D = Drainage Rating, 10–scale
T = Surfacing Thickness, inches
F = Fractured Faces, %

The speed and crown elements are reasonable since one expects faster deterioration at higher speeds and less deterioration with greater crown slopes. However, the others are more difficult to explain.

Fractured faces should improve performance, but the statistics indicate otherwise. Table 2 shows that Leavengood Lane has much lower fractured face counts than any other roads – 18% and 25% – while the lowest fractured face count on any other road in the study is 42%. Leavengood Lane was constructed from natural aggregate from a nearby hill. It has a favorable gradation and plasticity and it performs well in spite of its lack of fractured faces. This single aberration may account for this perplexing result. A regression was performed on the equation above, leaving out Leavengood Lane. This time, the p–value for fractured faces was 0.19, rather than the p–value of 0.07 with Leavengood Lane.

Greater surfacing thicknesses and better drainage should reduce deterioration, not increase it as this equation indicates. However, thicker surfaces are highly correlated with traffic volume and negatively correlated with good drainage, so this result is not so surprising. Substituting vehicles per day or ESALs per day yielded similar results: In both instances the R^2 value dropped to 44%; the p–values for drainage, fractured faces, and the traffic volume were now between 0.12 and 0.21; and the p–values for crown and speed remained below 0.002.

Forward and backward regressions on the thickness and traffic variables yielded the following equation with an R^2 value of 31%:

$$O_{DR} = –0.023 + S(–0.0023) + C(0.015) + E(–0.00016)$$

Where: O_{DR} = Overall condition deterioration rate, Rating points per Day
S = Median Speed, mph
C = Crown Slope, %
E = Equivalent Single Axle Loads (ESAL) per Day

Overall condition is clearly improved at lower speeds and with better crown, though other factors controlling overall deterioration are less obvious.

Potholes

Forward and backward regressions were performed on pothole formation rates as the dependent variable, starting with only those variables whose p–value was less than 0.1 when a regression was performed with that variable only. In both instances, ESAL/day and drainage were the only variables found to be significant, using a p–value of 0.1 as a cutoff. The R^2 value for the following equation is 66%:

$P_{DR} = 0.0546 + E(-0.00047) + D(-0.0075)$

Where: P_{DR} = Pothole deterioration rate, Rating points/Day
E = Equivalent Single Axle Loads (ESAL) per Day
D = Drainage Rating, 10–scale

This equation indicates that improved drainage leads to faster deterioration. Since drainage is correlated with surfacing thickness, another regression was performed using ESAL/day and surfacing thickness as the independent variables, yielding the following equation with a 62% R^2 value:

$P_{DR} = -0.0195 + E(-0.00052) + T(0.000845)$

Where: P_{DR} = Pothole deterioration rate, Rating points/Day
E = Equivalent Single Axle Loads (ESAL) per Day
T = Surfacing Thickness, inches

This equation indicates that pothole formation can be predicted based on surfacing thickness and heavy vehicle traffic, a reasonable result.

Rutting

Forward and backward regressions, beginning with the variables with a p–value of less than 0.1 when regressed individually, were performed on the rutting deterioration rates, as it was for the pothole rates. Backward regression yielded the following equation with an R^2 value of 63%:

$R_{DR} = -0.0070 + E(-0.00032) + SG(0.00029)$

Where: R_{DR} = Rutting deterioration rate, Rating points/Day
E = Equivalent Single Axle Loads (ESAL) per Day
SG = Subgrade PI

Forward regression yielded the following equation with an R^2 value of 65%:

$R_{DR} = 0.033 + E(-0.00032) + D(-0.0042) + SG(0.0034)$

Where: R_{DR} = Rutting deterioration rate, Rating points/Day
E = Equivalent Single Axle Loads (ESAL) per Day
D = Drainage Rating, 10–scale
SG = Subgrade PI

These equations predict that improving drainage makes the road deteriorate faster and that higher subgrade PI makes a road more resistant to rutting. Subgrade PI is highly correlated with traffic volumes and gravel thickness, so next these variables were added. Additionally, surfacing thickness was added since it is correlated with drainage. Both forward and backward regression with only these variables yielded the following equation with an R^2 value of 58%:

$R_{DR} = -0.011 + E(-0.00033) + T(0.0014)$

Where: R_{DR} = Rutting deterioration rate, Rating points/Day
E = Equivalent Single Axle Loads (ESAL) per Day
T = Surfacing Thickness, inches

This equation indicates that rutting can be predicted based on surfacing thickness and heavy vehicle traffic, a reasonable result.

Washboards

Forward and backward regressions, beginning with the variables with a p–value of less than 0.1 when regressed individually, were performed on the washboard deterioration rates. Using this approach, only coarse sands were found to be significant. The 85th percentile speed had a p–value of 0.11 but it was included since speed is clearly a factor in washboard formation, yielding the following equation with an R^2 value of 19%:

$$W_{DR} = 0.035 + CS(-0.0015) + HS(-0.0012)$$

Where: W_{DR} = Washboard deterioration rate, Rating points/Day
CS = Coarse Sand fraction, %
HS = 85th Percentile speed, mph

SUMMARY AND CONCLUSIONS

This paper evaluates one dry summer's data for gravel roads' short–term performance. Twenty gravel roads sections have been sampled, evaluated, and monitored on a weekly basis. Based on the preponderance of qualitative knowledge about how gravel roads perform, a number of variables believed to affect performance were selected. Potholes, rutting, washboards, and the roads' overall conditions have been rated using the PASER road rating system, modified for Wyoming's dry–freeze conditions.

Deterioration of gravel roads is a complex process which is affected by many factors. These factors can be broken down into general categories: traffic, gravel thickness, gravel properties, subgrade properties, surface geometry, and drainage. A number of these factors were evaluated and simple predictive equations were generated. The deterioration of gravel roads can be graphically represented as shown in Figures 2 and 3 below. Since this study is only based upon summer data, it should not be extrapolated to other times of year, nor should it be applied to other, wetter climates. As more data become available, more sophisticated analysis on year–round data will allow better predictions of various deterioration rates.

Primary factors affecting the deterioration rates of gravel roads have been identified. Those which have the largest effects on deterioration rates have been incorporated in preliminary equations predicting deterioration rates.

Overall condition ratings are affected mainly by vehicle speeds, truck traffic volumes, coarse sand fraction, subgrade plasticity index, crown slope, and drainage. A regression equation was generated using speed, crown slope, and truck traffic to predict the overall deterioration rate of gravel roads.

Pothole and rut ratings are affected by traffic volumes, surfacing thickness, coarse sand fraction, subgrade plasticity index, and drainage. Truck traffic and surfacing thickness are used to predict both rut and pothole formation. This is reasonable given that rutting is generally a structural failure and pothole formation is also related to structural issues in the road structure. However, one would also expect the crown slope and shape to affect pothole formation. Questions have been raised as to whether the crown measurement technique used in this study is adequate.

Washboard ratings are affected by vehicle speeds, coarse sand fraction, and surfacing plasticity index. The 85th percentile speed and coarse sand fraction are used to predict the washboard formation rate. It seems odd that traffic volume is not a significant factor affecting washboarding deterioration rates, but given that washboarding is largely due to a loss of or lack of cohesion in the surfacing rather than to any structural defects, this is not an entirely surprising result. It should be kept in mind that time is an inherent variable in calculating deterioration rates, so time may serve as a proxy for traffic closely enough that traffic volume is not a statistically significant factor affecting washboard formation.

The methods developed in this paper may be used and refined to generate better performance curves for gravel roads. Some things worked well, while others, such as crown slope and thicknesses, may need further refinement. Though sophisticated quality control analyses have not yet been performed, the subjective data collection is surprisingly accurate. It would not be possible for an outside observer to identify when one of the authors performed data collection, covering for the primary data collector when he was unavailable. However, this degree of calibration between the two data collectors is the result of extensive periods rating roads together and discussing the criteria and levels to which one assigns a rating to a road.

Though gravel roads are affected by many variables interacting in complex ways, performance can be predicted using relatively simple regression models. These models can be enhanced by collecting data through the entire year.

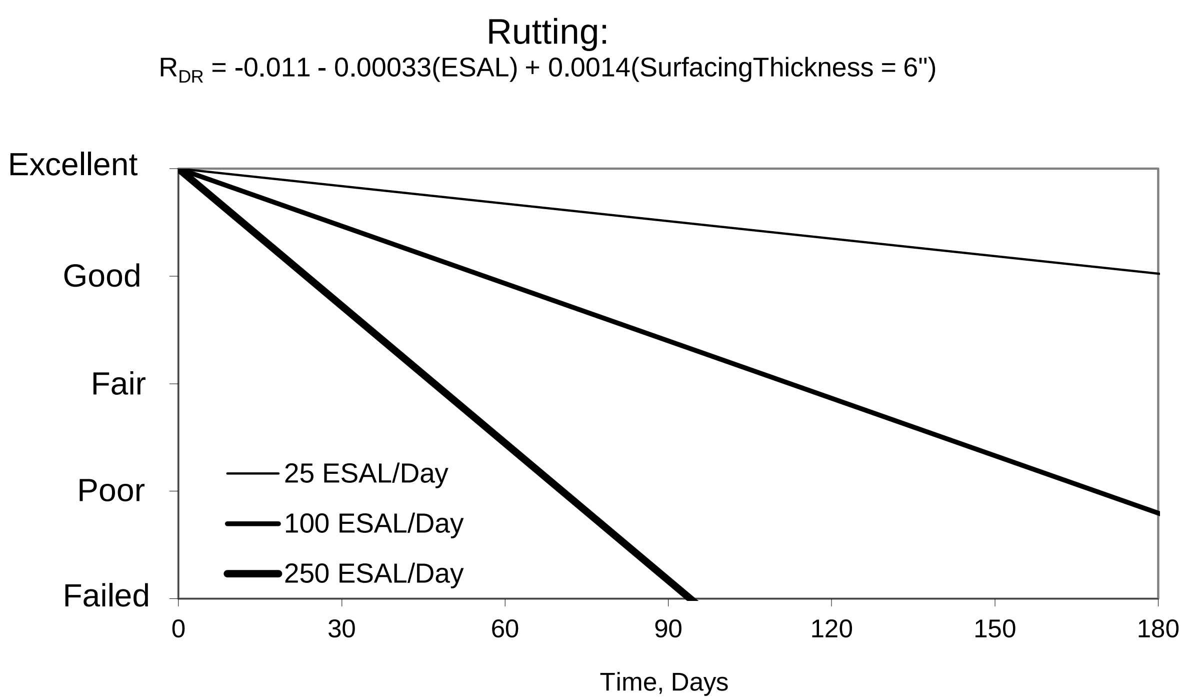


FIGURE 2. Rutting as a function of truck traffic

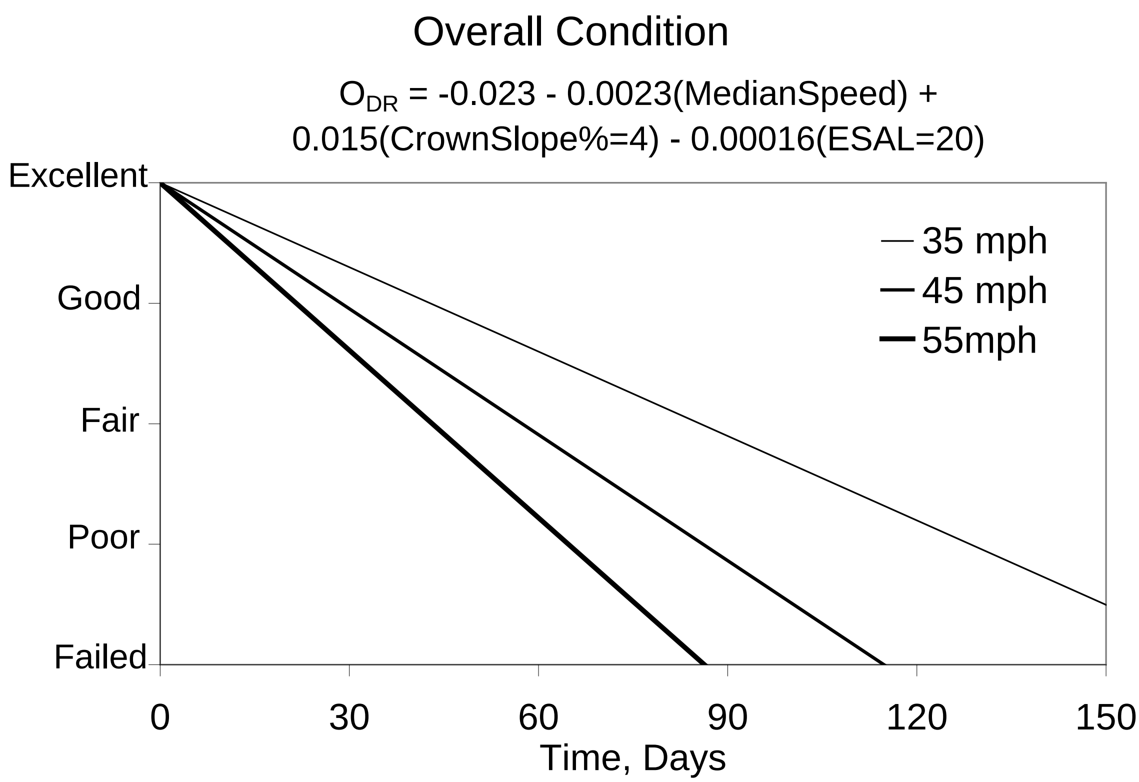


FIGURE 3. Overall condition as a function of median speed

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GRAVEL ROADS SURFACE PERFORMANCE MODELING

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ABSTRACT

Twenty gravel road study sections at 10 sites in north–central Wyoming were monitored from September 2005 through June 2006. “Windshield” ratings of the sections and field measurements were taken weekly. Surfacing gravel samples were collected and their gradations determined. Traffic speeds and volumes by class were collected with a two–tube system. Statistical analyses generated regression models that allow prediction of the service life of an unmaintained gravel road. Traffic speeds, traffic volumes, and surfacing gravel properties are shown to have the greatest influence on gravel roads’ deterioration rates. For these typical Wyoming county roads with good geometry, good drainage, and adequate gravel thicknesses, the typical failure mode is shown to be either potholes or washboards (corrugations). The typical life of gravel roads without maintenance was shown to be in the range of several months to a year. Climatic effects are shown to be related to precipitation more than seasonality, at least in Wyoming’s dry–freeze climate.

INTRODUCTION

The Wyoming Local Technical Assistance Program (LTAP) Center with support from the Wyoming Department of Transportation (WYDOT) and the Federal Highway Administration (FHWA) has assisted three Wyoming Counties – Sheridan, Johnson, and Carbon – with the implementation of an asset management system for their road networks. One of the goals of this project is to come up with optimization strategies for maintaining the counties' gravel roads. An integral aspect of optimizing road maintenance and construction activities is estimating how quickly a gravel road deteriorates under various conditions and circumstances. While deterioration of asphalt and concrete roads is reasonably well understood, there is little quantitative information on gravel roads' deterioration rates. This study begins filling that void. The results of this study will be used in condition–projection and optimization models to be developed as part of the Wyoming asset management program.

Managing and maintaining the vast mileage of gravel roads effectively has huge economic impacts, particularly for local and foreign governments without the resources to adequately investigate gravel roads' performance. The sheer volume of miles dictates that quickly evaluating gravel roads is necessary if any type of surfacing management system is to be implemented. Spending significant dollars per mile analyzing interstate highways is warranted, but a method of rating gravel roads quickly and inexpensively is necessary. While more labor-intensive rating methods are available *(1, 2)*, the Wyoming LTAP Center used a slightly modified version of the Wisconsin Transportation Information Center's PASER rating system *(3)* to evaluate the gravel roads in Sheridan, Johnson, and Carbon counties. Data collectors were hired and trained to rate the gravel roads *(4)*. The data used for this study were collected by a data collector hired and trained as part of the Wyoming LTAP Center's asset management program; 20 road sections were rated weekly from September 2005 through June 2006.

Background

Gravel roads' performance is affected by many factors – probably more than paved roads – with the single greatest difference being gravel roads' much greater maintenance frequency. Another major difference is gravel roads' greater susceptibility to moisture damage since their surfaces are more permeable, even with the best surfacing gravel. However, like paved roads, gravel roads deteriorate as a function of materials, construction, traffic, environment, and drainage.

Little data are available on gravel roads' performance, and particular mechanisms are generally not ascribed to their deterioration. Studies have examined the impact of loads and the adjustment of gravel thicknesses based on performance *(5)*, but predictions of the life of a gravel road are not readily available. However, there is considerable knowledge about the factors that contribute to gravel roads' deterioration. Too little binder contributes to washboarding, poor crown contributes to potholes, inadequate structural strength leads to rutting, and so on. There are clearly more variables affecting gravel roads than affect paved roads, making the prediction of their performance more difficult. When combined with the high mileage of these roads, this complexity makes predicting gravel roads' performance a particularly challenging endeavor. The fact remains that billions of dollars are spent maintaining gravel roads every year, and it would be wise to spend this money as effectively as possible. To achieve this goal, a critical question is: How long will a gravel road last under a given set of circumstances? This paper attempts to provide some guidance in answering that question.

Analytical Goals

The primary goal of this paper is to estimate the deterioration of gravel roads. Average deterioration rates for the 20 sections in this study are determined, and factors that influence how different roads deviate from these average rates are examined.

The effects of weather and maintenance on deterioration rates are examined. Given the more frequent maintenance and more rapid deterioration of gravel roads, weather, particularly precipitation, clearly affects the condition of gravel roads. Though little can be done to control the weather, it is important to assess its impact when analyzing gravel roads' performance.

Those responsible for maintaining gravel roads must decide whether it is worthwhile to haul more expensive gravel instead of making due with locally available materials. This paper attempts to provide some insights into making such decisions.

METHODS

This study is based on ratings of 20 study sections in Sheridan and Johnson counties, Wyoming. Material samples and traffic data were collected. Ratings took place weekly from September 2005 through June 2006.

Evaluation Standards and Training

As part of the Wyoming LTAP's asset management program, data collectors were hired and trained to rate, among other things, gravel road conditions. This report is based on data collected by a road rater who spent the previous summer evaluating gravel roads in Sheridan and Johnson Counties. The primary standards are those established in the PASER rating system *(3)*. Ratings are performed while driving slowly – 10 to 15 mph (15 – 25 km/hr) – over the study sections, noting the various characteristics of the road. This system rates road surface conditions as excellent, good, fair, poor, or failed. These ratings are related to the maintenance needed and to appropriate traffic speeds. Excellent roads need little or no maintenance; good roads need routine maintenance; fair roads need minor drainage work or additional gravel in some locations; poor roads are traveled at less than 25 mph (40 km/hr) and need additional aggregate or major drainage improvements; failed roads are difficult to travel and need complete reconstruction. Guidance on how to rate some features, such as gravel quality, was taken from various sources, particularly Skorseth and Selim *(6)*.

Measurements of crown slope, top width, and float were performed weekly. Crown was measured by placing a four–foot level on the crown slope in a location that appeared to be representative of the road section and measuring the elevation difference in four feet. Top width was measured from the shoulder hinges as shown in Skorseth and Selim *(6)*. Float was determined by collecting and weighing the loose material on the road's surface over the entire top width, even the outer portions that often had not been compacted by traffic.

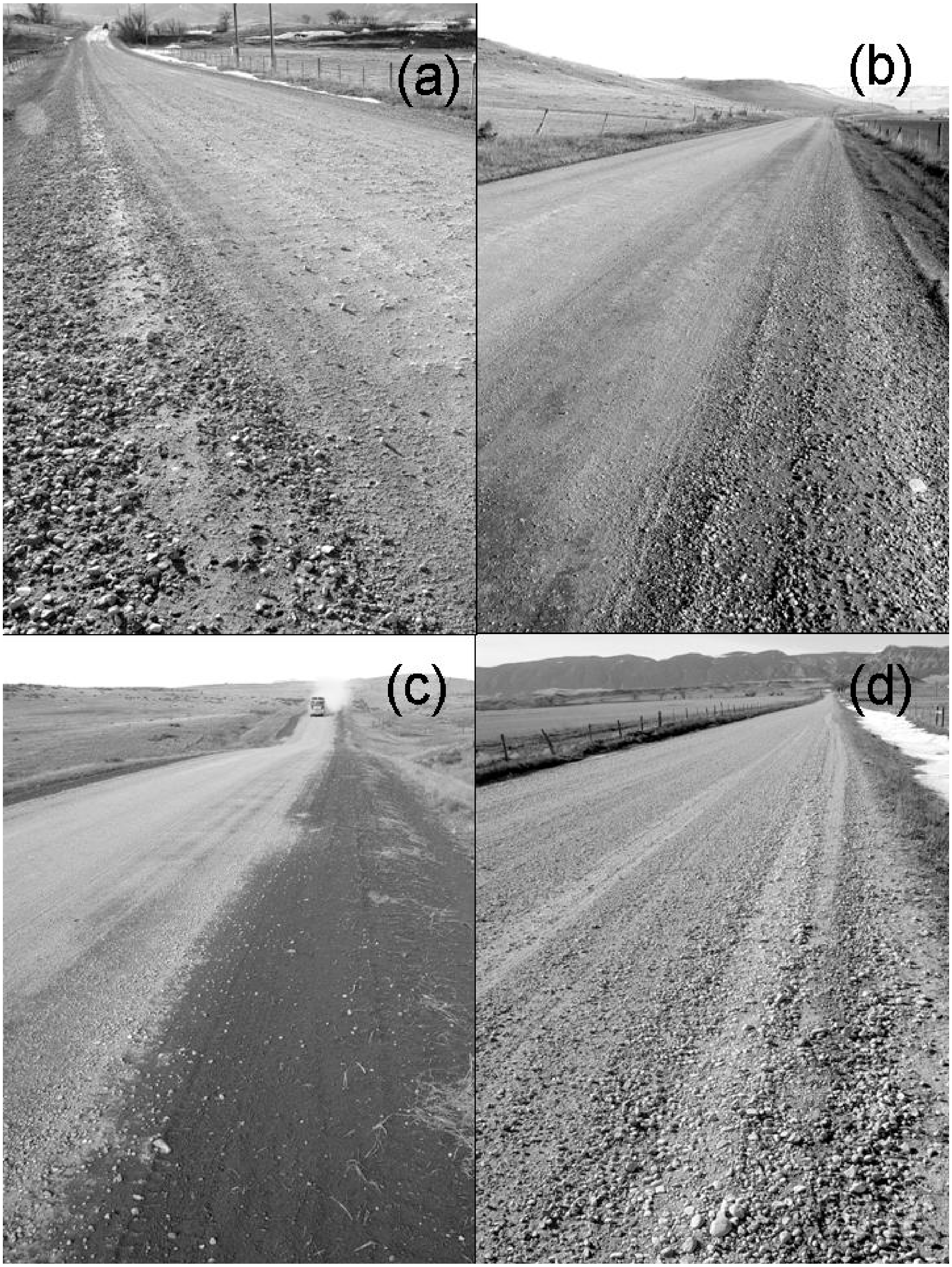


FIGURE 1. Study sections: (a) Wagonbox Road; (b) Lower Prairie Dog Road; (c) Passaic Road; and (d) Crazy Woman Canyon Road.

Study Sections

The 20 study sections are from ten different road sites; at each site, two adjacent 500-ft. sections were rated weekly. Figure 1 shows four of the study sections. Traffic data were collected during the summer of 2005 with a two–tube system that allowed for the determination of traffic speeds and axle spacing. ESALs per day were calculated using the FHWA axle classification scheme and the typical equivalent single axle loads (ESAL) for each class used by WYDOT for asphalt roads. Table 1 contains the traffic data and the percentages of gravel, coarse sand, fine sand, and fines in each section's surfacing gravel. All of the roads in the study are functionally "local" roads, with the exception of Lower Prairie Dog Road which is a "collector."

TABLE 1. Study sections' traffic and surfacing gravel gradations

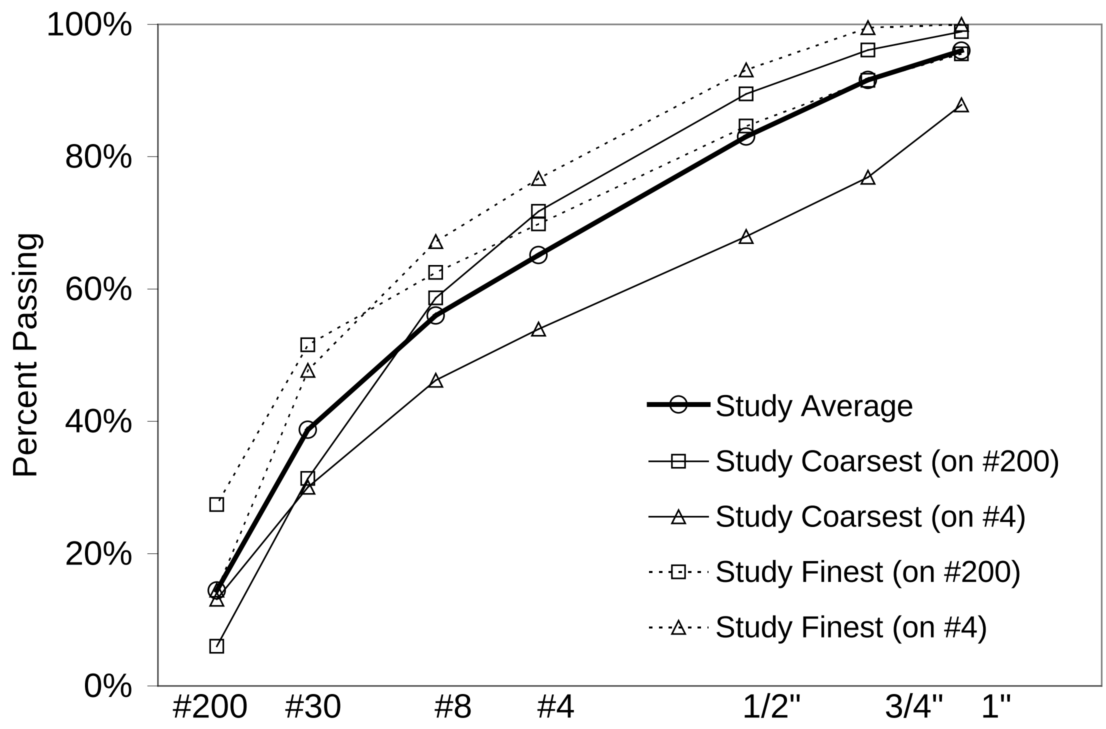
Road Name	Median Traffic Speed, mph	ADT, vpd	ESAL/day	Surfacing Gravel Percentages: Gravel: +#4	Coarse Sand: #4 - #30	Fine Sand: #30 - #200	Fines: - #200
Beaver Creek	36	524	62	42	23	18	17
Crazy Woman Canyon	26	198	29	37	18	23	22
Lower Prairie Dog	38	694	215	29	37	25	10
Passaic	38	98	20	24	31	32	12
Schoonover	28	230	75	32	31	25	12
Shell Creek	32	138	27	42	21	25	12
Soldier Creek	42	303	35	41	23	20	15
Tipperary	40	68	14	34	26	25	15
Ulm	37	62	8	25	30	30	15
Wagonbox	23	278	22	43	24	19	14

Note: 1 mph = 1.61 kph; #4 = 4.75 mm; #30 = 600 µm; #200 = 75 µm

Generally speaking, these sections are structurally adequate and well maintained with reasonably good geometry and drainage characteristics. The consistently good drainage and crown shapes on these sections makes predictions of roads' deterioration based on drainage difficult since all have reasonably good drainage characteristics. All sections are in the western Powder River Basin of north–central Wyoming, where they receive similar weather. The average precipitation for weather stations near the road study sections from September 1, 2005, through June 22, 2006, was 8.8-in. (224-mm). Of this, 2.8-in. (71-mm) fell during a three–week period in early October 2005 (Unpublished data received from Jodi Preston, Water Resources Data System, State Climate Office, 1000 E. University Ave., Department 3943, University of Wyoming, Laramie, June 29, 2006).

Sampling and Thickness Measurements

Gravel properties and thicknesses were sampled in January 2005. Gradations of coarse, average, and fine surfacing gravels are shown in Figure 2. It was relatively easy to obtain good surfacing samples. However, determining thicknesses of both surfacing gravel and total gravel was difficult. Lift boundaries, if they existed at all, were hard to ascertain. Both construction and maintenance practices typically practiced on county roads tend to mix adjoining lifts, and none of these roads have separation fabric keeping subgrade materials out of the gravel. Undoubtedly, thicker sections will perform better; however, this is not detected in the analyses performed. Two factors contribute to this problem: First is the aforementioned problem with the thickness data itself, and second, all of the study sections appear to be structurally adequate.



Note: #200 = 75 µm; #30 = 600 µm; #8 = 2.36 mm; #4 = 4.75 mm; 1/2” = 12.5 mm; 3/4" = 19 mm; 1” = 25 mm

FIGURE 2. Surfacing gravel gradations.

Analytical and Statistical Procedures

Data collected weekly, both windshield ratings and measurements, were compiled in a database. The ratings for each section were arranged chronologically. For each studied section, the occurrence of maintenance was noted and changes in the surface condition due to maintenance were not considered in subsequent analyses.

The average weekly changes for all 20 sections and four rated performance features – overall condition, potholes, rutting, and washboards (sometimes referred to as corrugations) – were calculated. The average of these changes was calculated for each feature, yielding an overall average deterioration rate based on an 8–scale with excellent roads being assigned a 10, good roads an 8, fair roads a 6, poor roads a 4, and failed roads a 2, for each feature. These average weekly deterioration rates allow the prediction of the average life of the segments’ surfaces.

Next, the deviation from these average deterioration rates for each segment was determined. One may assume that the deviations from the average deterioration rates are dependent on various factors, some of which have been evaluated in the course of this study. Finally, the various properties that may affect these deviations are assessed using regression analyses with independent variables such as surfacing gravel properties, traffic speeds, traffic volumes, and drainage, and dependent variables such as potholes and washboards. Knowing the average deterioration rate and the effect of various factors that cause a particular road to deviate from these average rates, the performance of a given gravel road section can be predicted.

ANALYSIS AND RESULTS

Ratings and Measurements

The average and standard deviation of the weekly ratings based on an 8–scale with10 as excellent and 2 as failed are presented in Table 2, which contains the average and standard deviation for each site's two rated sections. Differences between the two ratings at each site are small; they are caused by slight differences in subgrade support, surfacing thickness, and so on.

TABLE 2. Site averages and standard deviations of measurements and windshield ratings

Road		Overall	Potholes	Rutting	Washboards	Drainage	Dust	Crown	Crown Slope, %	Top Width, ft
Beaver Creek	*Avg*	8.3	8.0	8.3	8.3	8.7	9.9	8.9	3.0	23
	SD	0.6	1.0	0.7	0.9	1.0	0.3	1.2	0.4	1.0
Crazy Woman Canyon	*Avg*	7.4	7.1	7.9	7.9	10.0	7.8	7.9	2.8	26
	SD	1.1	1.4	0.9	1.3	0.2	1.4	1.1	0.6	2.4
Lower Prairie Dog	*Avg*	7.6	7.4	8.1	7.6	8.1	7.8	7.9	3.6	23
	SD	1.2	1.2	1.2	1.5	0.6	2.4	1.7	0.7	1.4
Passaic	*Avg*	8.0	8.1	8.2	8.0	10.0	8.4	8.3	3.3	18
	SD	0.6	1.1	0.5	1.0	0.0	1.6	1.2	0.6	1.0
Schoonover	*Avg*	7.8	7.9	8.1	7.9	10.0	7.6	7.9	2.7	20
	SD	0.5	1.3	0.7	1.0	0.0	1.3	0.9	0.6	0.7
Shell Creek	*Avg*	7.1	5.9	8.1	6.7	10.0	9.6	8.8	2.8	25
	SD	0.8	1.4	0.3	1.2	0.2	0.8	1.0	0.5	1.1
Soldier Creek	*Avg*	7.8	8.0	8.3	7.7	8.4	7.6	7.8	3.2	22
	SD	0.7	1.2	0.7	1.6	0.8	1.9	1.4	0.6	1.2
Tipperary	*Avg*	7.3	8.1	8.2	7.2	9.9	6.1	7.1	2.9	21
	SD	0.8	1.1	0.8	1.5	0.3	1.6	1.5	0.6	1.0
Ulm	*Avg*	8.0	8.4	8.3	8.1	9.9	7.5	7.8	3.4	19
	SD	0.5	1.1	0.9	0.9	0.3	1.9	1.4	0.5	1.0
Wagonbox	*Avg*	7.2	7.0	8.0	7.1	9.0	7.6	7.8	2.6	22
	SD	0.9	1.4	0.5	1.2	1.0	1.7	1.2	0.6	0.9
ALL	*Avg*	7.7	7.6	8.1	7.7	9.4	8.0	8.0	3.0	22
	SD	0.9	1.4	0.8	1.3	0.9	1.9	0.4	0.6	2.7

Note: 1 ft = 0.305 m

Table 2 highlights some of the limitations of the subsequent analyses. For example, there is not a lot of variability in crown ratings. Given the overall consistent maintenance of surface crown, this is not surprising; it makes it more difficult to attribute numerical values to the effects of crown shape since there is not much variability in the data.

Average Deterioration

The average deterioration in points per day on an 8–scale was determined for overall condition, potholes, rutting, and washboards. Based on these daily rates, the time to go from excellent–10 to failed–2 condition was linearly projected for each performance–related dependent variable. Table 3 contains the average deterioration rate in points per day on an 8–scale and the time in days it would take, on average, for each condition to deteriorate from excellent to failed condition if no maintenance were performed.

TABLE 3. Average deterioration rates and times to failure

	Overall	Potholes	Rutting	Washboards
Points per Day (on 8-scale)	-0.0250	-0.0397	-0.0216	-0.0429
Time to Failure, days	320	201	371	187

For the study sections, which are generally structurally adequate roads with good drainage, potholes and washboards appear to be the features that lead to failure most quickly. This agrees with the common sense observation that washboards and potholes are the main surfacing problems for this type of gravel road.

Average Weekly Changes

In an effort to determine which variables change significantly with time, the average change in the weekly ratings for all 20 sections was compared with the standard deviation of these changes. Figure 3 shows these average changes and their variability as expressed by the standard deviation.

As shown in Figure 3, some variables change significantly when compared with their variability, while the change in others is small compared with their standard deviation. This leads one to the conclusion that overall condition, potholes, washboards, and rutting deteriorate with time. However, loose aggregate, gravel quality, gravel sufficiency, crown, drainage, and dust ratings do not change significantly with time. Variation in these six variables may be attributed to noise in the data, rather than to any significant trends.

Seasonal, Precipitation, and Maintenance Effects

To assess seasonal and climate–related effects on gravel roads' performance and maintenance needs, precipitation throughout the study period was compared with both maintenance performed and surface conditions. Fortunately, all the study sections are in a region that receives similar weather. This allows one to make the imperfect assumption that all road segments receive the same weather, so the weather during a given period of time may be considered the same for all sections.

Various factors affect the deterioration of gravel roads. In dry climates, such as the Powder River Basin in north–central Wyoming, maintenance of gravel roads is performed when natural moisture is present. The interaction of precipitation and maintenance has a large influence on the performance of gravel roads. Figure 4 compares the rate of pothole formation to the average daily precipitation. When there has been recent rain, the formation of potholes takes place more quickly. The correlation between average weekly regional precipitation and the average pothole deterioration rate is 0.66; the correlation of rutting and precipitation is 0.28; of overall condition and precipitation is 0.31; and of washboards and precipitation is 0.04. Thus, potholes are significantly affected by precipitation, overall condition and rutting are somewhat affected by precipitation, and washboards are largely unaffected by precipitation.

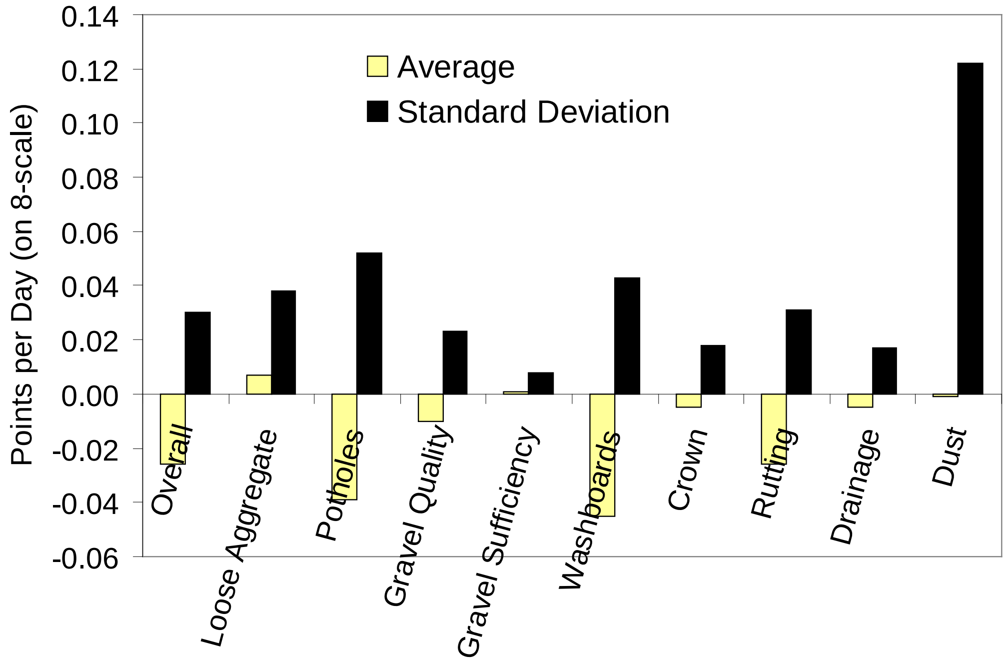
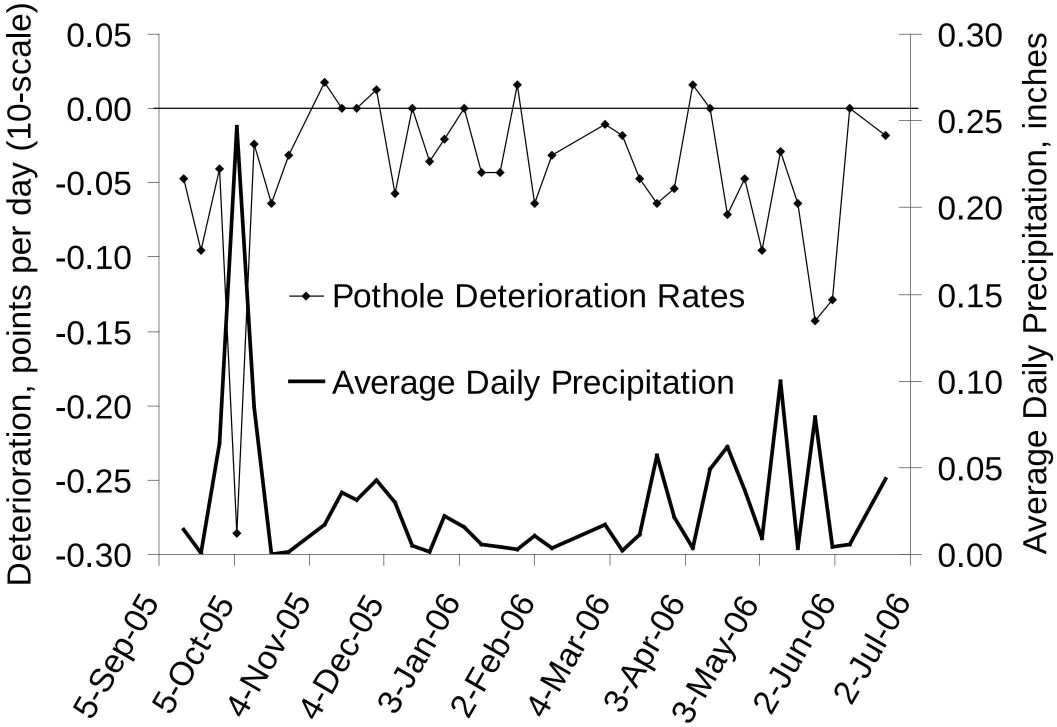


FIGURE 3. Change in weekly ratings.

Seasonal effects on gravel roads' performance are shown to be relatively minor; the primary environmental factor is precipitation as shown in Figure 4. Deterioration during the winter is less than during other seasons; the ground is frozen much of the time. Most of the deterioration occurs shortly after precipitation. The rainy period in early October 2005 led to rapid deterioration; the wet period in the spring of 2006 also led to increased deterioration, though the increase was not as dramatic as it was for the briefer but more intense rainy period in October.

Predicting deterioration based on seasonality alone is a difficult task, at least for a dry climate where precipitation occurs sporadically. Predicting the seasonal effects for a typical spring may be feasible, but the greater effects of occasional wet periods, such as the one in October 2005, are more difficult. This study focuses on average deterioration throughout the nine–month study period. For the purpose of this study – modeling the deterioration of gravel roads – using averages over this period are probably the best results that can be hoped for. While it might be possible to accurately predict the effects of significant precipitation events, this is of little value since the occurrence of such events cannot be predicted. However, deterioration can be predicted on a yearly basis.



Note: 1inch = 25.4 mm

FIGURE 4. Pothole deterioration rates and precipitation.

The seasonal issue becomes more complex when the interaction of precipitation and maintenance is considered. Since gravel roads (at least in Wyoming's dry climate) are usually maintained after rain when the gravel is damp, most gravel roads will begin their deterioration cycle in a damp, recently maintained state. The period over which this maintenance is effective is dependent on weather as much as it is on intrinsic properties of the road. With that said, some properties of the road itself will influence the rate of deterioration. Two situations are evaluated simultaneously in this study: the performance of dry roads between rainy periods and the performance of wet roads. Since the main goal of this study is to provide input deterioration rates for gravel road models, both of these factors are considered together. Beyond the average values for the life of an unmaintained gravel road, the factors that will increase or decrease the life of roads relative to these average lives are the main focus of this paper.

One of the initial goals of this study was to develop performance curves for gravel roads. Asphalt roads deteriorate slowly initially, then as cracks develop and water infiltrates, they deteriorate more quickly. The results above show that developing a shape for gravel roads' deterioration curves is likely to be a futile effort. The shape of these curves depends more on weather than on any common trends in gravel roads' deterioration. Nonetheless, there are some characteristics of gravel roads that may affect their deterioration rates. The following analyses attempt to quantify some of these effects.

Regression Analyses of Individual Independent Variables

Independent Variable Coefficients

The first regressions performed used each individual independent variable and several surfacing material-related interactions as predictors of the four dependent variables, overall condition, potholes, washboards, and rutting. Table 4 shows the coefficients for the independent variables with p–values less than 0.05 predicting the deterioration rate based on regressions of each dependent variable with a single independent variable.

TABLE 4. Coefficients of independent variables with p–values less than 0.05 predicting deterioration rates in points per day on an 8–scale

Independent Variables	**Overall**	**Potholes**	**Washboards**	**Rutting**
Median Speed, mph	-0.011	-0.011	-0.023	-0.0070
85th % Speed, mph	--	--	-0.014	--
Average Daily Traffic, vpd	-0.00028	--	--	--
Truck Traffic, ESAL/day	-0.0012	-0.0011	--	--
(ADT x ESAL/day)/1000	-0.0018	-0.0016	--	--
Coarse Sand:Fines	-0.044	-0.044	--	--
Gravel Quality	--	--	--	0.070
Gravel Sufficiency	--	-0.63	--	--
Crown	-0.68	--	--	--
Drainage	0.093	0.076	0.14	--
Crown Slope	-0.55	--	-0.84	--

Note: 1 mph = 1.61 kph

Traffic. Increasing speeds and traffic volumes lead to negative coefficients, indicating that higher speeds and volumes lead to more rapid deterioration.

Surfacing Gravel Ratios. The ratio of coarse sand to fines in the surfacing gravel has a negative coefficient, indicating that as this ratio becomes larger, deterioration occurs more quickly. Thus, as the surfacing gravel becomes finer the ratios become smaller and deterioration becomes faster, indicating that finer gravel performs better. More coarse sand leads to faster deterioration, while more fines make a more durable gravel surface. This agrees with the common observation that naturally occurring gravels in this area usually contain insufficient binder and plasticity.

Subjective Windshield Ratings. The coefficients for gravel quality and drainage are positive, an intuitively correct result. As these variables receive higher ratings, the deterioration rates become slower. However, the gravel sufficiency and crown ratings have negative coefficients, indicating that with better ratings, the road surface deteriorates faster, a counter–intuitive result. All the roads in this study are structurally adequate and have reasonably good geometry; they have sufficient gravel quantity and a good crown, so it is not surprising that the evaluator was not able to make accurate distinctions between the different road sections.

Crown Slope Measurements. The crown slope measurements have a negative coefficient, indicating that roads deteriorate faster with greater crown slopes. This highlights the difficulty in getting good crown measurements with a four–foot level as well as the relatively small variability in crown slope from section to section. The lowest average crown slope for the study sections was 2.6%, while the highest was 3.6%.

This small variability, along with relatively little precipitation, makes it difficult to adequately assess the effect of crown on gravel roads' surfacing durability.

Regression Analyses with Multiple Independent Variables

The preceding analyses used only a single independent variable to predict deterioration rates. However, deterioration of gravel roads is a complex process with many factors affecting the service life of an unmaintained gravel road. All independent variables are used together in an attempt to predict their comprehensive effects. Both forward and backward stepwise regressions were used to derive the models in Table 5, which contains the constants and coefficients for the various regression models derived to predict deterioration rates.

TABLE 5. Regression models of deterioration rates in points per day on an 8–scale

	Y–int.	**Median Traffic Speed, mph**	**ESAL x ADT**	**ESAL**	**S:M**	**CxF:M**	**R^2**
Overall	0.366	–0.00853	$-4.57\text{x}10^{-6}$	0.00236	–0.121	0.00686	80%
Potholes	0.516	–0.0113	$-1.07\text{x}10^{-6}$	—	–0.150	0.00838	70%
Rutting	0.166	–0.00696	—	—	0.109	–0.183	53%
Washboards	1.127	–0.0251	—	—	–0.287	0.0157	74%

Note: S = sand percentage #4 to #200 (4.75 mm to 75 µm), C = coarse sand #4 to #30 (4.75 mm to 600 µm), F = fine sand #30 to #200 (600 µm to 75 µm), and M = fines –#200 (<75 µm), all expressed in percentages as whole numbers.

Comprehensive Model Predictions

Using the regression models generated above, the life of gravel roads can be plotted by keeping most of the independent variables constant and varying one independent variable. For gradation ratios, three gradations are used to generate the materials ratios found in the regression models. The gradations used are those in Figure 2 using Study Coarsest on #4 (4.75-mm), Study Average, and Study Finest on #200 (75 µm). Figure 5 illustrates the use of two of the models in Table 5 to predict deterioration.

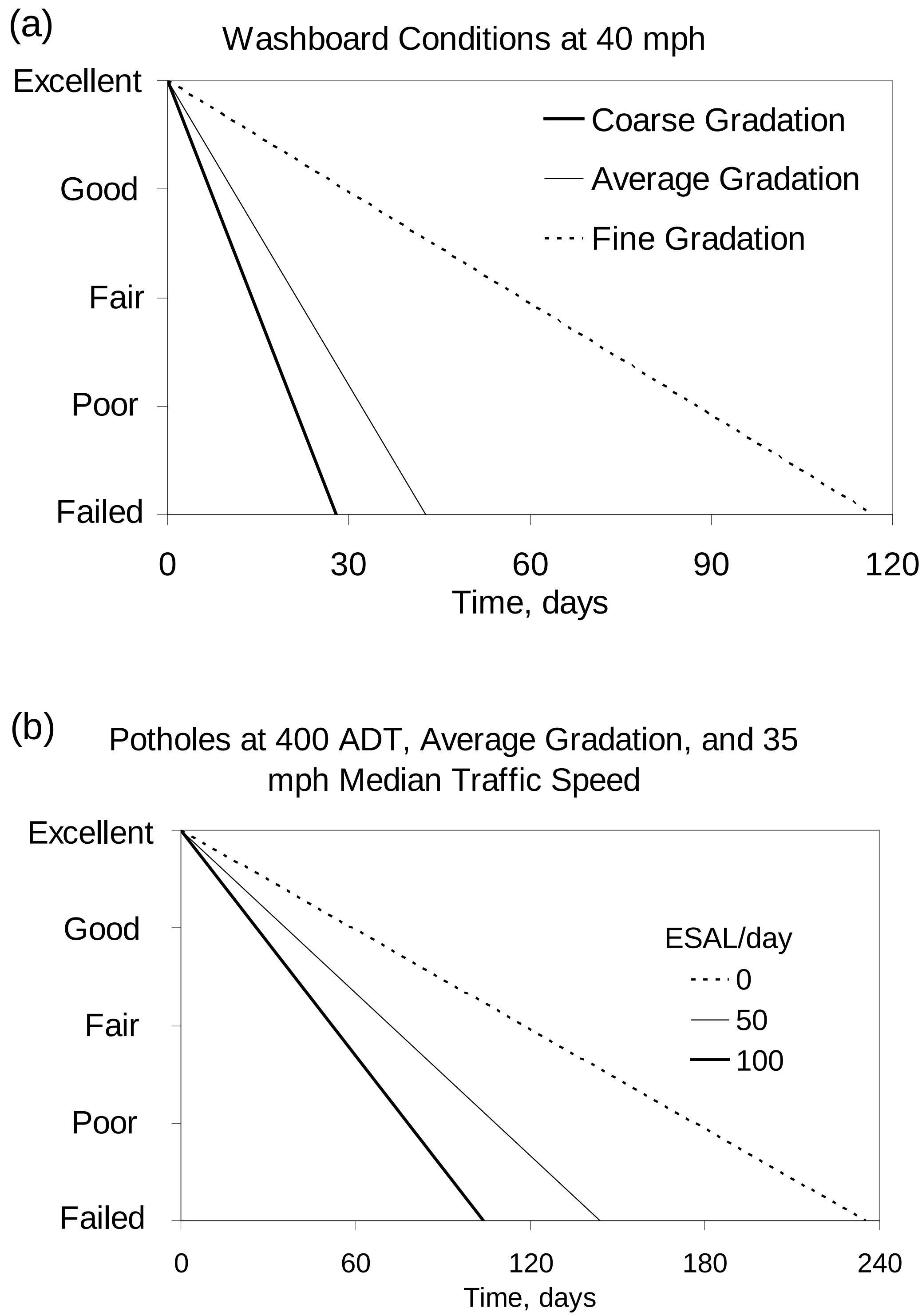


FIGURE 5. Washboard (a) and pothole (b) formation as predicted by multi–variable models

Factors Affecting Deterioration Rates

Traffic Effects

Traffic Speed. Unfortunately two factors are at play when discussing the effects of speed on gravel roads: First, higher vehicle speeds cause a gravel road to deteriorate faster; and second, vehicle speeds are reduced when surface conditions deteriorate. This study uses traffic speeds collected during single one–week periods. To more accurately establish the interaction of these two offsetting factors relating traffic speed to road conditions, traffic speeds would have to be monitored continuously as the road is being rated to evaluate the influence of road conditions on traffic speed. The data used in this paper only allow one to evaluate the influence of vehicle speed on deterioration rates but not the effect of road conditions on vehicle speeds. In spite of these difficulties, it is very clear from the models shown in Table 5 that gravel roads deteriorate significantly faster with increasing traffic speeds.

Traffic Volume. Traffic volume of both total vehicles and heavy vehicles is shown to affect the life of gravel roads. For many of the regressions performed, truck traffic, as expressed by the daily ESALs times the average daily traffic, provided the best predictive value, indicating that both total vehicle and truck traffic volumes influence gravel roads' deterioration. Clearly increasing traffic volume accelerates gravel roads' deterioration, and this is borne out in this study.

Gravel Effects

Gravel Thickness. No significant effects can be attributed to either total gravel or surfacing thicknesses. Two factors may contribute to this incongruous result. First, the lifts are not easily identified during sampling, leading to inaccurate measurement of the gravel's thickness. Second, all the roads in this study appear to be structurally adequate, so distresses generally are not due to insufficient gravel.

Surfacing Gravel Gradations. No significant effects can be attributed to the portion of the total gravel that is coarse, coarse sand, fine sand, or fines. However, when ratios of, for example, sand to fines were used as independent variables, a number of statistically significant relationships were established. The ratio of sand to fines was found to be a significant predictor of the deterioration rates for all four dependent variables. In general, finer mixes performed better, though the simple linear regressions used in this study are not sophisticated enough to isolate the effects of gravel as well as they might. Clearly, surfacing gravel could be too fine to perform optimally but the simple linear regressions used in this paper do not reflect this. The overall implication of these results is that the surfacing gravels used in this study are generally on the coarse side. This is not surprising since most Wyoming gravel sources need cohesive fines added to them to make a good surfacing gravel.

Drainage Effects

Crown and Crown Slope. The crown windshield ratings show very little variability and are not found to be statistically significant predictors of any distresses, with the possible exception of overall condition. Crown slope is shown to have a negative effect on performance – higher crown slopes lead to faster deterioration. This may be due, at least in part, to the fact that the fastest deteriorating road, Lower Prairie Dog, also has the greatest slope. Slope has a relatively small statistical effect on differences in deterioration rates since there is little variability in the measured crown slopes.

Drainage. The windshield drainage ratings are shown to have only minor effects on deterioration. As for the crown slope, the drainage ratings have little variability, which is a reasonable outcome since all the roads in the study have reasonably good drainage. While there is some improvement in performance due to superior drainage, the study sections do not have enough variation in drainage to provide a good analysis of the benefits of improved drainage.

Comprehensive Effects

When all the independent variables are considered, traffic speed is the most statistically important predictor of performance. Traffic volumes and gravel properties also have significant effects on deterioration.

The deterioration of the overall condition, potholes, and washboards, with R^2 values of 80%, 70%, and 74%, respectively, can be predicted reasonably well using traffic speed, traffic volumes, and gravel properties. Rutting, with an R^2 value of only 53%, is not predicted as well. This indicates that surfacing defects are well detected using the methods of this study, but longer-term structural problems are not well identified, perhaps due to the study's relatively short duration of nine months.

When traffic speed is not used as an independent variable, the predictive capability of the regression models is reduced significantly. Overall condition, potholes, washboards, and rutting have R^2 values of 70%, 47%, 52%, and 42%, respectively, when traffic speed is not used.

SUMMARY AND CONCLUSIONS

This paper evaluates the influence of various properties on gravel roads' deterioration. Twenty gravel road sections in north–central Wyoming, a dry–freeze climate, were rated weekly from September 2005 through June 2006. The road sections in the study all have good geometric properties. Four dependent variables are shown to deteriorate significantly with time: overall condition, potholes, rutting, and washboards (corrugations). Climatic effects, traffic characteristics, gravel properties, gravel thicknesses, and drainage are all used with varying degrees of success as tools for predicting a gravel road's surfacing life.

Models predicting deterioration rates based on traffic speeds, traffic volumes, and surfacing gravel material properties were derived. Gravel thicknesses were not shown to influence the performance of gravel roads; this is probably due to the structural adequacy of all the study sections and the difficulty in accurately measuring lift thicknesses. The predictive capacity of drainage and crown could not be conclusively demonstrated due to their consistency from section to section. The following conclusions can be drawn from the analyses performed in this study:

- The following three variables have major influences on the rate at which gravel roads deteriorate:
    - Traffic speed has a great influence on the predicted deterioration rates. As speeds increase, the rate of deterioration also increases, indicating that faster traffic does significantly more damage to gravel roads. This agrees with the on–the–ground observation made by many Wyoming county road and bridge workers that slower traffic does much less damage to gravel roads.
    - Traffic volume also has a major influence on deterioration rates, as one would expect. Both more vehicles per day and more heavy truck traffic accelerated deterioration. For most models, the greatest predictive value was achieved by multiplying the truck traffic as measured in ESALs per day by the average daily traffic in vehicles per day.
    - Surfacing gravel properties were shown to influence deterioration rates. The surfacing gravel was split into four categories: gravel, coarse sand, fine sand, and fines. Though the absolute portions of each of these materials were not shown to be significant, the ratios of these portions did yield significant results. The ratio of total sand to fines and the ratio of fine sand times coarse sand to fines were significant predictors: finer materials performed better. This

is not surprising since most Wyoming gravels need to be mixed with additional cohesive materials to make good surfacing gravel.

- Recent precipitation, more than seasonal effects, has a large influence on the rate of deterioration of gravel roads, at least in a dry–freeze climate. Faster deterioration rates were associated with and proportional to the amount of precipitation that had fallen in the previous week.
- Ratings performed by a lay person were generally good and consistent for ride characteristics such as washboards and potholes, but not as good for predictive variables such as gravel quality and crown.
- The average life of a gravel road without maintenance was found to be from several weeks to about a year, depending mainly on the road's traffic and material characteristics. The models developed in this study can be used to predict the service life of a gravel road.

RECOMMENDATIONS

In the course of this study, numerous lessons were learned that should improve predictions of gravel road surfaces' life, as described below:

- Surfacing evaluations should be geared toward the gravel roads' typical failure modes: potholes, washboards (corrugations), and rutting.
- Traffic speeds and volume should be monitored continuously to assess the effect of deteriorating surfacing conditions on traffic speeds and volumes.
- Features such as crown, drainage, gravel quality, and gravel quantity should be evaluated by professionals with considerable gravel road experience though they do not need to be evaluated frequently.
- Gravel should be sampled based on depth rather than by lifts since it is often difficult or impossible to discern lifts in gravel roads.
- To ascertain the effects of drainage, roads that are otherwise similar in their gravel and geometry but have significant differences in drainage should be studied. In Wyoming, this might mean evaluating the same road where it is adjacent to an irrigation ditch compared with an area where the irrigation ditch is far from the road. Similar approaches to evaluating the effectiveness of different maintenance techniques or crown could also be developed.
- More comprehensive means of quantifying the materials properties that influence the performance of gravel road surfaces should be developed.

The techniques described in this study could be used to quantify the factors controlling gravel roads' deterioration, thereby increasing the practitioners' ability to optimize the expenditure of limited funds.

Acknowledgements

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A.4 GRAVEL ROADS IMPROVEMENT RECOMMENDATION PROCEDURE

To assess the needs of the counties' gravel roads, first, the most recent ratings for each road segment were compiled in a database. Loose aggregate, dust, drainage, and ride quality were assessed and recommended maintenance activities were selected for each of these distresses. The activity with the highest cost was selected as the recommended maintenance activity for each segment. Conceptually, different maintenance is needed to correct different deficiencies; for the purposes of this analysis it is assumed that the more expensive maintenance activity will correct the observed deficiencies.

The road conditions affecting ride quality were determined, generating a term for each segment referred to as the surface serviceability index (SSI). The SSI was calculated using weighted averages. Twenty percent of the SSI is the overall condition rating, and 40% each is from the worst two of the rutting, washboards, and potholes ratings. Minimum SSIs for each functional classification were established (see Table A.4a) at minimal, recommended, and optimal levels (throughout this report, the 'recommended' SSI levels are used except as otherwise noted); for each segment, the calculated SSI was compared with the minimum SSI for that class. Those segments that were below the established threshold were identified as needing surfacing repairs.

Table A.4a Minimum surface serviceability index (SSI) by gravel road functional class

	Description			***Numeric Values***		
Functional Class	*Minimal*	*Recommended*	*Optimal*	*Min.*	*Rec.*	*Opt.*
Resource	Failed/Poor	Poor	Poor/Fair	3	4	5
Local	Poor	Poor/Fair	Fair	4	5	6
Minor Collector	Poor/Fair	Fair	Fair/Good	5	6	7
Major Collector	Fair	Fair/Good	Good	6	7	8

Once the segments with deficient SSIs were identified, the appropriate treatment was selected based on the segments' distresses and the maintenance strategies in Table A.4b for overall condition, potholes, washboards, and rutting.

Using the distress levels for loose aggregate, drainage, and dust, additional maintenance activities were generated, again using Table A.4b.

Using the costs from Table A.4c, the maintenance activity with the highest cost was selected for each segment. These costs, as well as the other inputs shown in the tables in this appendix, can easily be changed in future evaluations.

Table A.4b Gravel roads recommended maintenance activities based on distress conditions

Distress & Condition	Resource	Local	Minor Collector	Major Collector
Overall				
Excellent	None	None	None	None
Good	None	None	None	None
Fair	None	None	None	Maintaining
Poor	None	Maintaining	Spot Maintenance	Regravel
Failed	Maintaining	Regravel	Rehabilitate	Rehabilitate
Loose Aggregate				
Excellent	None	None	None	None
Good	None	None	None	None
Fair	None	None	None	None
Poor	None	None	Maintaining	Maintaining
Failed	None	Maintaining	Spot Maintenance	Spot Maintenance
Potholes				
Excellent	None	None	None	None
Good	None	None	None	None
Fair	None	Reshaping	Regravel	Spot Repair
Poor	Maintaining	Spot Repair	Spot Repair	Rehabilitate
Failed	Spot Maintenance	Rehabilitate	Reconstruct	Reconstruct
Washboards				
Excellent	None	None	None	None
Good	None	None	None	None
Fair	None	Maintaining	Maintaining	Maintaining
Poor	Maintaining	Spot Maintenance	Regravel	Regravel
Failed	Maintaining	Regravel	Regravel	Regravel
Rutting				
Excellent	None	None	None	None
Good	None	None	None	None
Fair	None	Spot Maintenance	Spot Maintenance	Regravel
Poor	Spot Maintenance	Regravel	Regravel	Rehabilitate
Failed	Regravel	Rehabilitate	Rehabilitate	Reconstruct
Drainage				
Excellent	None	None	None	None
Good	None	None	None	None
Fair	None	Clean Ditches	Clean Ditches	Clean Ditches
Poor	Clean Ditches	Reshape Ditches	Reshape Ditches	Reshape Ditches
Failed	Reshape Ditches	Reshape Ditches	Spot Repair	Spot Repair
Dust				
Excellent	None	None	None	None
Good	None	None	None	None
Fair	None	None	None	None
Poor	None	Dust Suppressant	Dust Suppressant	Dust Suppressant
Failed	Dust Suppressant	Dust Suppressant	Dust Suppressant	Dust Suppressant

Table A.4c Gravel roads maintenance activity costs per mile

	Resource	Local	Minor Collector	Major Collector
Maintaining	$400	$400	$400	$400
Spot Maintenance	$1,350	$1,350	$1,350	$1,350
Dust Suppressant	$1,500	$5,000	$7,000	$8,000
Regravel	$10,000	$12,000	$15,000	$18,000
Spot Repair	$30,000	$50,000	$70,000	$90,000
Rehabilitate	$100,000	$150,000	$175,000	$200,000
Reconstruct	$400,000	$800,000	$1,000,000	$1,200,000
Clean Ditches	$500	$500	$500	$500
Reshape Ditches	$2,000	$3,000	$3,500	$4,000
Mow and Spray	$500	$500	$500	$500
Snow Plowing	$50	$50	$75	$75

A.5 ASPHALT ROADS IMPROVEMENT RECOMMENDATION PROCEDURE

To assess the needs of the counties' asphalt roads, first, the most recent ratings for each road segment were compiled into a data base. Drainage was assessed and recommended maintenance activities were selected to address drainage issues.

A user condition index (UCI) was generated to assess which roads should be recommended for improvements. Table A.5a contains the weightings for each distress used to calculate the UCI. The aging crack rating is the worst of the ratings for slippage cracks, reflective cracks, transverse cracks, longitudinal cracks, and block cracks.

TableA.5a Distress weightings for asphalt roads user condition index (UCI)

Overall	Polishing	Raveling	Flushing	Rutting	Distortion	Patching	Potholes	Aging Cracks	Fatigue Cracks
0%	2%	2%	2%	12%	5%	15%	27%	9%	21%

Next, minimum UCIs were established for each functional class (see Table A.5b). Those segments that were below the established threshold were identified as needing surfacing repairs. (Except as otherwise noted, all figures in this report are based on the recommended user condition levels from Table A.5b.) The maintenance activities recommended by Table A.5c for each distress and functional class were determined for each road segment.

Table A.5b Minimum asphalt roads user condition levels

	Description			Numeric Values		
Functional Class	**Minimal**	**Recommended**	**Optimal**	**Min.**	**Rec.**	**Opt.**
Local	Fair	Fair	Good	4	5	6
Minor Collector	Fair	Good	Good	5	6	7
Major Collector	Good	Good	Very Good	6	7	8

The costs of all the recommended activities were compared, and the activity with the highest cost was selected as the recommended activity. This was done for all road segments that have a UCI less than the UCI recommended for their functional class in Table A.5b. Costs are based on the values in Table A.5d. All values in the tables in this appendix can easily be changed in future evaluations.

Table A.5c Recommended asphalt roads maintenance activities based on distresses

Distress & Condition	Local	Minor Collector	Major Collector
Overall			
Excellent-10	None	None	None
Excellent-9	None	None	None
Very Good-8	None	None	None
Good-7	None	None	None
Good-6	None	None	None
Fair-5	None	None	None
Fair-4	None	Chip Seal	Chip Seal
Poor-3	Chip Seal	Thin Overlay - 1½	Thick Overlay - 3
Very Poor-2	Thick Overlay - 3	Thick Overlay - 3	Rehabilitation
Failed-1	Rehabilitation	Rehabilitation	Reconstruction
Drainage			
Excellent	None	None	None
Good	None	None	None
Fair	None	Clean Ditches	Clean Ditches
Poor	Clean Ditches	Reshape Ditches	Reshape Ditches
Failed	Replace Culverts	Rehabilitation	Rehabilitation
Polishing			
None	None	None	None
Low	None	None	None
Medium	None	Chip Seal	Chip Seal
High	Chip Seal	Chip Seal	Chip Seal
Raveling			
None	None	None	None
Low	None	None	None
Medium	None	None	None
High	Fog Seal	Chip Seal	Chip Seal
Flushing			
None	None	None	None
Low	None	None	None
Medium	None	None	None
High	Chip Seal	Chip Seal	Chip Seal

Table A.5c Recommended asphalt roads maintenance activities based on distresses (continued)

Distress & Condition	Local	Minor Collector	Major Collector
Rutting			
None	None	None	None
Low	None	None	None
Medium	Slurry Seal	Slurry Seal	Thin Overlay - 1½
High	Thin Overlay - 1½	Thin Overlay - 1½	Thick Overlay - 3
Distortion			
None	None	None	None
Low	None	None	None
Medium	None	Minor Patching	Minor Patching
High	Minor Patching	Major Patching	Major Patching
Patching			
None	None	None	None
Low	None	None	Minor Patching
Medium	Minor Patching	Major Patching	Chip Seal
High	Chip Seal	Chip Seal	Slurry Seal
Potholes			
None	None	None	None
Low	None	Minor Patching	Minor Patching
Medium	Minor Patching	Major Patching	Major Patching
High	Thin Overlay - 1½	Thick Overlay - 3	Rehabilitation
Alligator Cracks			
None	None	None	None
Low	None	None	Chip Seal
Medium	Chip Seal	Chip Seal	Thick Overlay - 3
High	Thin Overlay - 1½	Thick Overlay - 3	Reconstruction
Aging Cracks			
None	None	None	None
Low	None	None	None
Medium	Crack Seal	Crack Seal	Crack Seal
High	Chip Seal	Thin Overlay - 1½	Thick Overlay - 3

Table A.5d Asphalt roads maintenance and construction activity costs per mile per event

Activity	Local	Minor Collector	Major Collector
Clean Ditches	$500	$500	$500
Reshape Ditches	$3,000	$3,500	$4,000
Replace Culverts	$10,000	$12,000	$12,000
Mow and Spray	$500	$500	$500
Snow Plowing	$50	$75	$75
Minor Patching	$1,000	$1,200	$1,500
Major Patching	$5,000	$6,000	$6,000
Fog Seal	$3,000	$3,500	$3,500
Crack Seal	$10,000	$12,000	$12,000
Chip Seal	$15,000	$20,000	$20,000
Slurry Seal	$30,000	$35,000	$35,000
Thin Overlay - 1½	$90,000	$100,000	$100,000
Thick Overlay - 3	$150,000	$160,000	$160,000
Rehabilitation	$500,000	$550,000	$550,000
Reconstruction	$900,000	$1,300,000	$1,500,000

A.6 GRAVEL ROADS ANNUAL CONSTRUCTION AND ROUTINE MAINTENANCE COST PROCEDURE

Routine maintenance and construction needs have been estimated for gravel roads. First, the miles in each functional class were determined, based on the GPS and GIS information collected by T^2. Next, construction and routine maintenance activity costs were estimated (see Table A.4c).

The frequencies at which these activities need to be performed were estimated for each activity and functional class (see Table A.6a).

Multiplying the events per year by the cost per event results in a total average annual construction and routine maintenance cost per mile (see Table A.6b). (These are average, system–wide projections: $12,000 per mile for reconstruction of major collectors implies reconstructing 1% of the major collectors for $1,200,000 per mile; not reconstructing every mile of major collectors for $12,000 per mile.) These costs were combined in five classes: routine plowing, mowing, and spraying; routine drainage maintenance; routine surface maintenance; repairs; and reconstruction. The first two categories are self–explanatory. Routine surface maintenance includes maintaining and reshaping roads, spot maintenance, applying dust suppressant, and regraveling roads. Repairs includes spot repair and rehabilitation – significant repairs that result in functional and/or structural improvements. Reconstruction includes rebuilding the entire road, usually with some geometric changes and usually yielding both functional and structural improvements.

TableA.6a Gravel roads construction and routine maintenance activity events per year

ACTIVITY	**Resource**	**Local**	**Minor Collector**	**Major Collector**
Maintaining	0.100	2.000	4.000	6.000
Spot Maintenance	0.020	0.100	0.300	0.500
Dust Suppressant	0.000	0.050	0.100	0.150
Regravel	0.005	0.083	0.150	0.200
Spot Repair	0.000	0.007	0.009	0.011
Rehabilitate	0.000	0.004	0.007	0.010
Reconstruct	0.000	0.001	0.002	0.003
Clean Ditches	0.050	0.143	0.143	0.143
Reshape Ditches	0.020	0.050	0.050	0.050
Mow and Spray	0.200	0.500	0.800	0.900
Snow Plowing	0.000	4.000	7.000	10.000

Table A.6b Estimated annual gravel roads construction and routine maintenance costs per mile

	Resource	Local	Minor Collector	Major Collector
Plowing, Mowing and Spraying	$100	$450	$925	$1,200
Drainage Maintenance	$65	$221	$247	$271
Surface Maintenance	$117	$2,185	$4,955	$7,875
MAINTENANCE SUBTOTAL	$282	$2,856	$6,127	$9,346
Repairs	$0	$950	$1,855	$2,990
Reconstruction	$0	$800	$2,000	$3,600
CONSTRUCTION SUBTOTAL	$0	$1,750	$3,855	$6,590
TOTAL	**$282**	**$4,606**	**$9,982**	**$15,936**

A.7 ASPHALT ROADS ANNUAL CONSTRUCTION AND ROUTINE MAINTENANCE COST PROCEDURE

Routine maintenance and construction needs have been estimated for asphalt roads. First, the miles in each functional class were determined, based on the GPS and GIS information collected by T^2. Next, construction and routine maintenance activity costs were estimated (see Table A.5d).

The frequencies at which these activities need to be performed were estimated for each activity and functional class (see Table A.7a).

Table A.7a Asphalt roads construction and routine maintenance activity events per year

Events/Year	Local	Minor Collector	Major Collector
Clean Ditches	0.143	0.143	0.143
Reshape Ditches	0.067	0.067	0.067
Replace Culverts	0.040	0.040	0.040
Mow and Spray	0.500	0.800	0.900
Snow Plowing	4.000	7.000	10.000
Minor Patching	0.100	0.050	0.050
Major Patching	0.010	0.020	0.020
Fog Seal	0.010	0.000	0.000
Crack Seal	0.060	0.100	0.100
Chip Seal	0.050	0.040	0.040
Slurry Seal	0.000	0.000	0.020
Thin Overlay - 1½	0.020	0.010	0.000
Thick Overlay - 3	0.000	0.010	0.020
Rehabilitation	0.000	0.002	0.002
Reconstruction	0.001	0.002	0.003

Multiplying the cost per event by the events per year results in total costs per year per mile for each functional class and activity (see Table A.7b). These were broken down into six categories: drainage work; routine mowing, spraying, and plowing; patching; seal coats and crack seals; overlays; and major improvements.

Table A.7b Annual asphalt roads construction and routine maintenance costs per mile

Activity Type	Local	Minor Collector	Major Collector
Drainage	$671	$785	$818
Plowing, Mowing and Spraying	$450	$925	$1,200
Patching	$150	$180	$195
Seals	$1,380	$2,000	$2,700
MAINTENANCE	$2,651	$3,890	$4,913
Overlays	$1,800	$2,600	$3,200
Major Improvements	$900	$3,425	$5,600
CONSTRUCTION	$2,700	$6,025	$8,800
TOTALS	**$5,351**	**$9,915**	**$13,713**

A.8 GRAVEL ROADS LONG–TERM MODELING

The long–term condition of the gravel roads is estimated by using a multiple increment process, with each increment lasting one month and a 20-year analysis period. Figure A.8a summarizes the modeling process used to project the unpaved roads' conditions at a selected funding level.

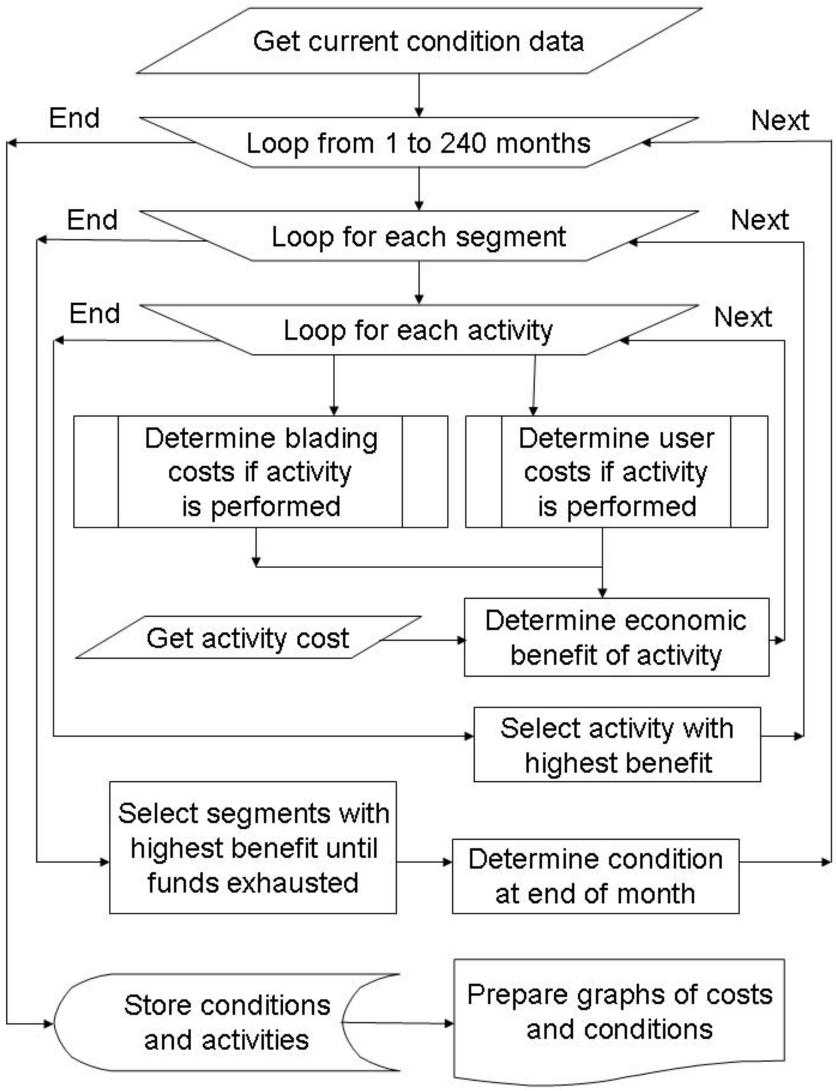

Figure A.8a Long–term unpaved roads modeling flowchart.

As shown in Figure A.8a, the modeling process has three nested loops. The outer loop is the month; the next loop is for each segment, and the inner loop is for each potential maintenance activity.

The effects on user and routine maintaining costs of each maintenance or construction activity, except routine maintaining, on each section are estimated each month. Maintaining costs are considered with user costs since they are performed so frequently; it is assumed that basic serviceability is to be achieved by routine maintaining. In addition, maintaining is performed when moisture conditions permit, not when it is determined that they are necessary, so including maintaining in scheduled maintenance activities is not practical. Performing other maintenance or construction activities will reduce the frequency of maintaining and reduce user costs. The reduction in maintaining and user costs is compared with the cost of performing higher level maintenance or construction activities. The benefit/cost ratio times the square root of cost savings is used to rank the various maintenance activities that might be performed on a given segment each month.

The optimal maintenance activity is selected for each segment each month. For road segments in good condition, it may not be cost effective to perform any maintenance. For segments that may realize a net benefit from maintenance, those that derive the greatest benefit are selected first. If the road network is in good enough condition and sufficient funds are available, it may not be cost effective to spend all the available funds. In this situation, the amount spent on maintenance and construction may be less than the amount available. The available funds for the month in question are reduced by the cost of performing the maintenance or construction activities with the greatest benefits. This process is repeated, each time selecting the remaining maintenance activity that provides the greatest benefit until all profitable activities have been performed or the available funds for that month are exhausted.

The maintenance activities performed are not eligible to be performed again during the projected life of each maintenance activity, as shown in Table A.8b. For example, the life of reshaping a local road is 24 months, so when reshaping is selected for a local road segment, it cannot be performed again for 24 months.

Table A.8b Life of maintenance activities in months by functional class

	Resource	Local	Minor Collector	Major Collector
Clean Culverts and Ditches	120	84	84	84
Reshape Ditches	240	240	240	240
Pulling Shoulders	300	84	60	36
Reshaping	180	60	36	24
Dust Suppressant	60	36	30	24
Regravel	360	180	120	84
Replace Culverts	480	480	480	480
Spot Repair	780	600	480	360
Rehabilitate	900	720	600	480
Reconstruct	1,200	900	720	600

Once the maintenance activities to be performed each month are selected, the effects of performing these activities are simulated. Projected improvements in the roads' conditions are applied and used for the subsequent month's analysis. Standard deterioration rates are interpolated based on last year's performance study (Huntington and Ksaibati 2007), using the values shown in Table A.8c.

Table A.8c Standard distress deterioration in points per month on an 8–scale

	Overall	*Gravel Quality*	*Gravel Quantity*	*Crown*	*Drainage*	*Loose Aggregate*	*Potholes*	*Washboards*	*Rutting*	*Dust*
Resource	0.013	0.027	0.013	0.067	0.013	0.013	0.027	0.007	0.013	0.007
Local	0.044	0.044	0.056	0.133	0.017	0.044	0.044	0.067	0.033	0.013
Minor Collector	0.056	0.067	0.095	0.167	0.022	0.095	0.056	0.095	0.044	0.017
Major Collector	0.067	0.095	0.133	0.222	0.027	0.133	0.067	0.133	0.056	0.022

These deterioration rates are adjusted by a durability factor which depends on the distresses believed to affect the durability of the road surface: overall condition, gravel quality, gravel sufficiency, crown, drainage, and dust. The durability improvement factors are interpolated from Table A.8d. Multiplying the standard deterioration rate by the durability factor yields a deterioration rate for each month, segment, and distress, allowing the estimation of the subsequent month's distress conditions.

Table A.8d Durability improvement factors by distress condition

	2 - Failed	**4 - Poor**	**6 - Fair**	**8 - Good**	**10 - Excellent**
Overall	0.50	0.70	0.90	1.00	1.10
Gravel Quality	0.30	0.50	0.70	1.00	1.20
Gravel Quantity	0.40	0.60	0.80	1.00	1.20
Crown	0.30	0.50	0.70	1.00	1.20
Drainage	0.50	0.70	0.90	1.00	1.10

Once the maintenance or construction activities to be performed each month have been selected and the effects of these activities have been estimated, the process is repeated for the next month. This incremental process is repeated for 240 months, 20 years. The costs incurred and the resulting surfacing serviceability indexes are plotted, showing the relationship between the amounts spent on taking care of the roads and the resulting quality of the roads' surfaces.

A.9 ASPHALT ROADS LONG–TERM MODELING

The condition of each county's asphalt roads is predicted over a forty year period and maintenance activities are recommended, all within budgetary constraints, using an asphalt model developed at the Wyoming T^2/LTAP Center. Figure A.9a is a flowchart of the model. The referenced subroutines are described in Table A.9a.

In summary, the model selects maintenance activities based on those that provide the greatest improvement in user conditions within budgetary constraints on a system–wide basis. As a consequence of the maintenance activities performed, the rate at which the road surfaces deteriorate is reduced. The surface conditions at the end of the year are established, and maintenance activities are selected for the following year, based on these revised surface conditions.

The field data collected as part of the asset management program are used as a starting point for the first of the 40 one-year iterations of the system performance model. The field data imported into the model are described in Table A.9b. The assumed input variable types are listed in Table A.9c, while the tables of individual inputs are shown in Tables A.5d and A.9d through A.9k.

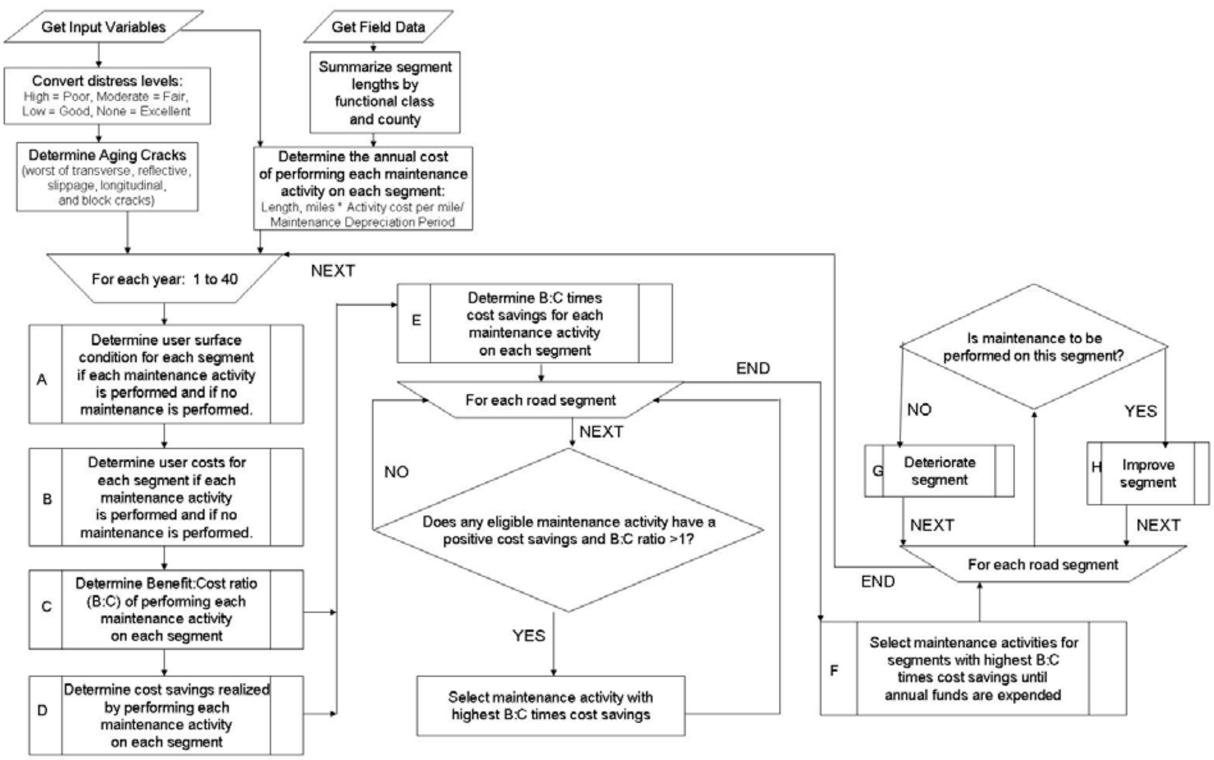

Figure A.9a Asphalt system–prediction model flowchart.

Table A.9a Asphalt system–prediction subroutines

Subroutine		Procedures
A	Determine user surface condition for each segment if each maintenance activity is performed and if no maintenance is performed.	1) Determine distress conditions resulting if each maintenance activity is performed, based on current distress levels and the 'Maintenance Improvement Levels.' 2) Determine the user condition index (UCI) based on the resulting distresses and the 'User Condition Weights.'
B	Determine user costs for each segment if each maintenance activity is performed and if no maintenance is performed.	1) Determine the user cost multiplier (UCM) based on the UCI and the User Cost Multipliers, interpolating between the values in the table. 2) Determine the user cost on each segment with each maintenance activity, based on the traffic volume (assumed for the functional class or from traffic counts), the UCM, the base cost per vmt (vehicle mile traveled), and the length of the segment.
C	Determine the Benefit:Cost ratio (B:C) of performing each maintenance activity on each segment.	1) Determine the B:C ratio for each segment and maintenance activity by dividing [the annual difference in the user cost between performing each maintenance activity and not performing any maintenance minus the annual cost of the maintenance activity] by [the annual cost of the maintenance activity.
D	Determine the cost savings realized by performing each maintenance activity on each segment.	1) Determine the cost savings for each segment and maintenance activity by subtracting [the annual cost of the maintenance activity] from [the difference in the user cost between performing each maintenance activity and not performing any maintenance].
E	Determine B:C times cost savings for each maintenance activity on each segment.	1) Multiply the B:C ratio from subroutine [C] by the cost savings from subroutine [D].
F	Select maintenance activities for segments with the highest B:C times cost savings until annual funds are expended.	1) Select the segment and maintenance activity with the highest B:C times cost savings. 2) Reduce the available budget by the cost of this maintenance activity. 3) Repeat until annual funds are depleted. 4) Make the selected maintenance activities ineligible for performance during the maintenance depreciation period for the performed maintenance activity. 5) Reduce the deterioration rate for the maintained segments by the depreciation reduction factor appropriate for the maintained segment, pro–rated for each year of the maintenance depreciation period, approaching the distress deterioration rate at the end of the maintenance depreciation period.
G	Deteriorate unmaintained segments.	1) Reduce the distress condition by the adjusted distress deterioration rate.
H	Improve maintained segments.	1) Improve the distress conditions by the values in the Maintenance Improvement Levels and reduce the distress deterioration rates.

Table A.9b Asset management program field data imported into long–term model

Unique ID (for the GIS software: one for each one–mile segment)
Segment ID (County, Road Number, Segment Number)
Road Name
Road Number
Segment length, miles
County
Functional Class: Local, Minor Collector, Major Collector
Measurements: Top width, Crown slope
'Windshield' ratings: Overall, Drainage, Polishing, Raveling, Flushing, Rutting, Distortion, Patching, Potholes, Transverse cracks, Reflective cracks, Slippage cracks, Longitudinal cracks, Block cracks, Alligator cracks

Table A.9c Assumed input variable tables

Counties' Annual Asphalt Budgets
Functional Class Assumed Traffic Volumes
User Cost Multipliers & Base Cost per vmt (vehicle mile traveled)
User Condition Weights
Maintenance Improvement Levels
Distress Deterioration Rates
Maintenance Depreciation Period
Depreciation Reduction
Maintenance Activity Costs

Table A.9d Counties' annual asphalt budgets (example)

Annual Asphalt Budget		
Carbon	Johnson	Sheridan
$100,000	$250,000	$50,000

Table A.9e Assumed traffic volume based on functional classes

Vehicles per Day (vpd)		
Local	Minor Collector	Major Collector
50	150	400

Table A.9f Base cost per vmt and user cost multipliers based on user condition indexes

Condition	UCI	User Cost Multiplier
1-Failed	1	12.000
2-Very Poor	2	7.000
3-Poor	3	4.000
4-Fair	4	2.500
5-Fair	5	1.800
6-Good	6	1.300
7-Good	7	1.100
8-Very Good	8	1.030
9-Excellent	9	1.010
10-Excellent	10	1.000

Base cost per vehicle mile	$0.30

Table A.9g User condition weights for determining user condition indexes

Distress	*Overall*	*Drainage*	*Polishing*	*Ravelling*	*Flushing*	*Rutting*	*Distortion*	*Patching*	*Potholes*	*Fatigue Cracks*	*Aging Cracks*
Percentage	0%	5%	2%	2%	2%	12%	5%	15%	27%	21%	9%

Table A.9h Maintenance improvement levels by maintenance activity and distress

Improvement (10-scale) per Event	*Overall*	*Drainage*	*Polishing*	*Raveling*	*Flushing*	*Rutting*	*Distortion*	*Patching*	*Potholes*	*Fatigue Cracks*	*Aging Cracks*
Clean Ditches	0	1	0	0	0	0	0	0	0	0	0
Reshape Ditches	0	3	0	0	0	0	0	0	0	0	0
Replace Culverts	0	6	0	0	0	0	0	0	0	0	0
Mow and Spray	0	0	0	0	0	0	0	0	0	0	0
Snow Plowing	0	0	0	0	0	0	0	0	0	0	0
Minor Patching	0	0	0	0	0	0	0	0	2	0	0
Major Patching	1	0	0	0	0	0	0	1	4	0	0
Fog Seal	1	0	0	4	0	0	0	1	0	1	2
Crack Seal	1	0	0	0	0	0	0	1	0	2	6
Chip Seal	2	0	9	5	2	0	0	3	1	3	4
Slurry Seal	3	0	9	6	2	4	2	4	2	4	5
Thin Overlay - 1½	5	0	9	9	9	7	7	8	6	5	7
Thick Overlay - 3	6	0	9	9	9	8	8	8	8	6	8
Rehabilitation	6	6	9	9	9	6	8	8	8	7	8
Reconstruction	9	9	9	9	9	9	9	9	9	9	9

Table A.9i Distress base deterioration rates

Distress	Deterioration Rate, Points per Year Local	Minor Collector	Major Collector
Overall	0.30	0.36	0.45
Drainage	0.30	0.30	0.30
Polishing	0.23	0.36	0.45
Raveling	0.36	0.36	0.36
Flushing	0.09	0.09	0.09
Rutting	0.23	0.36	0.45
Distortion	0.09	0.12	0.18
Patching	0.18	0.23	0.30
Potholes	0.45	0.50	0.60
Fatigue Cracks	0.36	0.45	0.60
Aging Cracks	0.45	0.45	0.45

Table A.9j Maintenance depreciation period

Maintenance Activity	Treatment Life, years Local	Minor Collector	Major Collector
Clean Ditches	3	3	3
Reshape Ditches	10	10	10
Replace Culverts	40	40	40
Mow and Spray	1	1	1
Snow Plowing	0.1	0.1	0.1
Minor Patching	2	1	1
Major Patching	5	3	3
Fog Seal	3	2	2
Crack Seal	10	8	7
Chip Seal	11	9	8
Slurry Seal	8	7	6
Thin Overlay - 1½	25	20	17
Thick Overlay - 3	40	30	25
Rehabilitation	100	80	70
Reconstruction	200	125	100

Table A.9k Depreciation reduction factors

Maintenance Activity	**Depreciation Reduction Factor**
Clean Ditches	0.95
Reshape Ditches	0.88
Replace Culverts	0.70
Mow and Spray	1.00
Snow Plowing	1.00
Minor Patching	0.95
Major Patching	0.90
Fog Seal	0.80
Crack Seal	0.60
Chip Seal	0.55
Slurry Seal	0.50
Thin Overlay - 1½	0.30
Thick Overlay - 3	0.20
Rehabilitation	0.10
Reconstruction	0.10

Once the 40-year simulations have been run, charts are generated that plot the annual costs for asphalt roads and the resulting asphalt surface conditions over the 40-year analysis period.

A.10 GRAVEL ROADS RECOMMENDED IMPROVEMENTS

Table A.10a Carbon County gravel roads recommended improvements by road

Road Name	Road Number	Functional Class	Miles	Cost
Wamsutter	701	Major Collector	8.0	$545,281
Twenty Mile/JO	605S	Minor Collector	2.0	$347,946
Twenty Mile/JO	605N	Major Collector	4.2	$209,491
Old Lincoln Highway	316W	Minor Collector	2.8	$136,554
Elk Mtn.-Arlington/Wagon Hound	402	Local	3.6	$112,314
Poison Butte/Government	700	Minor Collector	3.0	$103,251
Jack Creek	500	Major Collector	2.0	$99,507
Ferris Crossing	340	Major Collector	1.0	$86,528
Pass Creek	404	Minor Collector	1.0	$68,146
Buzzard/Willow	497	Resource	4.8	$47,968
North Spring Creek	385	Resource	4.0	$31,188
Paintbrush	730	Local	2.0	$23,444
Dry Creek	103	Resource	2.0	$19,567
Sage Creek	401	Major Collector	2.0	$18,356
Medicine Bow Ranger Station	101	Minor Collector	1.0	$14,974
Savage Ranch	347S	Local	2.0	$13,274
McCarty Canyon	503	Local	1.0	$12,010
Stock Drive	215S	Minor Collector	0.7	$11,005
Shirley Ridge	2W	Resource	1.0	$9,939
Stone Ranch	272	Local	1.0	$2,932
		TOTAL	48.9	$1,913,675

Table A.10b Carbon County gravel roads recommended improvements by functional class and improvement activity

Maintenance Activity	Recommended Improvement Costs				
	Resource	Local	Minor Collector	Major Collector	TOTAL
Spot Maintenance	$1,299	$2,691	$1,235	$0	$5,225
Dust Suppressant	$0	$0	$0	$24,947	$24,947
Regravel	$107,362	$59,024	$54,951	$39,812	$261,149
Spot Repair	$0	$0	$277,745	$890,101	$1,167,845
Rehabilitate	$0	$96,382	$347,946	$0	$444,328
Clean Ditches	$0	$0	$0	$480	$480
Reshape Ditches	$0	$5,877	$0	$3,823	$9,700
TOTAL	$108,661	$163,974	$681,876	$959,163	$1,913,675

Maintenance Activity	Miles Improved				
	Resource	Local	Minor Collector	Major Collector	TOTAL
Spot Maintenance	1.0	2.0	0.9	0.0	4
Dust Suppressant	0.0	0.0	0.0	3.1	3
Regravel	10.7	4.9	3.7	2.2	22
Spot Repair	0.0	0.0	4.0	9.9	14
Rehabilitate	0.0	0.6	2.0	0.0	3
Clean Ditches	0.0	0.0	0.0	1.0	1
Reshape Ditches	0.0	2.0	0.0	1.0	3
TOTAL	12	10	11	17	49

Table A.10c Johnson County gravel roads recommended improvements by road

Road Name	Road Number	Functional Class	Miles	Cost
TW	204	Major Collector	4.8	$300,044
Schoonover	204B	Major Collector	24.2	$193,333
190	190	Local	3.0	$160,963
Upper Powder River	195	Minor Collector	9.0	$158,974
Dead Horse	259	Major Collector	6.1	$131,791
Shell Creek	85	Minor Collector	1.4	$96,025
Dry Creek	204A	Local	0.5	$68,839
TTT	51	Minor Collector	5.5	$67,811
Tipperary	54	Minor Collector	4.0	$60,118
Wagon Box	55A	Minor Collector	2.3	$34,657
Buffalo-Sussex Cutoff	86	Minor Collector	2.6	$25,420
Hazelton	3	Minor Collector	4.1	$20,748
Kumor	40	Minor Collector	2.0	$15,633
Klondike	132	Minor Collector	1.0	$15,214
Slip	67	Minor Collector	1.0	$15,160
Lower Piney Creek	32	Minor Collector	0.5	$7,830
Crazy Woman Canyon	14	Local	0.4	$4,555
Rock Creek	1	Minor Collector	2.0	$1,004
		TOTAL	74.3	$1,378,118

Table A.10d Johnson County gravel roads recommended improvements by functional class and improvement activity

Maintenance Activity	Recommended Improvement Costs				
	Resource	Local	Minor Collector	Major Collector	TOTAL
Spot Maintenance	$0	$0	$3,440	$0	$3,440
Dust Suppressant	$0	$0	$20,837	$233,746	$254,584
Regravel	$0	$28,794	$322,948	$12,569	$364,311
Spot Repair	$0	$0	$165,301	$366,602	$531,903
Rehabilitate	$0	$214,842	$0	$0	$214,842
Clean Ditches	$0	$0	$2,523	$0	$2,523
Reshape Ditches	$0	$2,971	$3,545	$0	$6,516
TOTAL	$0	$246,607	$518,594	$612,917	$1,378,118

Maintenance Activity	Miles Improved				
	Resource	Local	Minor Collector	Major Collector	TOTAL
Spot Maintenance	0.0	0.0	2.5	0.0	3
Dust Suppressant	0.0	0.0	3.0	29.2	32
Regravel	0.0	2.4	21.5	0.7	25
Spot Repair	0.0	0.0	2.4	4.1	6
Rehabilitate	0.0	1.4	0.0	0.0	1
Clean Ditches	0.0	0.0	5.0	0.0	5
Reshape Ditches	0.0	1.0	1.0	0.0	2
TOTAL	0	5	35	34	74

Table A.10e Sheridan County gravel roads recommended improvements by road

Road Name	Road Number	Functional Class	Miles	Cost
Lower Prairie Dog	1211	Major Collector	14.8	$804,439
Red Grade	26	Various	10.5	$492,658
Keystone	98	Local	3.0	$306,848
Upper Powder River	273	Minor Collector	5.1	$302,576
Lower Powder River	269	Minor Collector	4.0	$281,654
Passaic	255	Minor Collector	4.0	$224,878
Wild Horse	38	Minor Collector	3.9	$220,038
Box Cross	111	Major Collector	0.8	$165,431
Coutant Creek	114	Minor Collector	2.3	$87,974
Beatty Gulch	1231	Minor Collector	3.0	$82,936
East Pass Creek	21	Local	0.6	$82,632
South Prong	293	Minor Collector	1.0	$71,504
Coal Creek	195	Minor Collector	2.0	$70,928
Wolf Creek	67	Local	1.0	$49,900
Dutch Creek	161	Minor Collector	3.0	$45,211
Badger Creek	122	Minor Collector	2.0	$29,691
Little Goose Canyon	77	Resource	2.8	$27,179
Wildcat	84	Minor Collector	3.1	$21,918
Ranchester - Five Mile Extention	120A	Resource	1.8	$17,870
Dow Prong	151	Minor Collector	1.1	$16,105
PK Lane	52	Resource	2.3	$15,310
Upper Prairie Dog	127	Minor Collector	1.0	$14,767
Jim Creek	34	Local	1.5	$14,254
Evans	75	Resource	1.4	$11,303
Twin Creek	140	Resource	1.0	$9,628
Lodore Avenue	4	Local	0.1	$8,978
SR - Buffalo Creek	86	Local	1.0	$4,984
Bald Mountain - Dayton	100	Resource	1.1	$2,136
Beatty Spur	108	Minor Collector	1.1	$1,419
Downer's Addition (Mydland)	80	Local	0.6	$766
		TOTAL	80.7	$3,485,914

Table A.10f Sheridan County gravel road recommended improvements by functional class and improvement activity

Maintenance Activity	Resource	Local	Minor Collector	Major Collector	TOTAL
Spot Maintenance	$0	$766	$4,164	$0	$4,930
Dust Suppressant	$0	$8,081	$20,564	$24,435	$53,081
Regravel	$103,282	$23,727	$185,159	$143,367	$455,536
Spot Repair	$0	$49,900	$1,331,377	$433,957	$1,815,233
Rehabilitate	$0	$386,486	$0	$761,260	$1,147,747
Clean Ditches	$0	$0	$579	$491	$1,070
Reshape Ditches	$4,883	$0	$3,435	$0	$8,318
TOTAL	$108,165	$468,961	$1,545,278	$1,363,510	$3,485,914

	Miles Improved				
Maintenance Activity	Resource	Local	Minor Collector	Major Collector	TOTAL
Spot Maintenance	0.0	0.6	3.1	0.0	4
Dust Suppressant	0.0	1.6	2.9	3.1	8
Regravel	10.3	2.0	12.3	8.0	33
Spot Repair	0.0	1.0	19.0	4.8	25
Rehabilitate	0.0	2.6	0.0	3.8	6
Clean Ditches	0.0	0.0	1.2	1.0	2
Reshape Ditches	2.4	0.0	1.0	0.0	3
TOTAL	13	8	40	21	81

A.11 ASPHALT ROADS RECOMMENDED IMPROVEMENTS

Table A.11a Asphalt roads cost of improvements at various condition levels

		Patching Costs	
	Minimal	*Recommended*	*Optimal*
Carbon	$0	$0	$0
Johnson	$0	$0	$5,964
Sheridan	$0	$0	$0
		Seal Coat Costs	
	Minimal	*Recommended*	*Optimal*
Carbon	$68,635	$196,055	$373,703
Johnson	$0	$0	$323,965
Sheridan	$0	$0	$29,620
		Overlay Costs	
	Minimal	*Recommended*	*Optimal*
Carbon	$231,200	$240,640	$533,850
Johnson	$652,800	$2,976,290	$4,377,250
Sheridan	$237,920	$691,240	$907,900
		Major Improvement Costs	
	Minimal	*Recommended*	*Optimal*
Carbon	$547,250	$547,250	$547,250
Johnson	$16,581,000	$41,736,000	$41,736,000
Sheridan	$0	$0	$0
		Total Improvement Costs	
	Minimal	*Recommended*	*Optimal*
Carbon	$847,085	**$983,945**	$1,454,803
Johnson	$17,233,800	**$44,712,290**	$46,443,179
Sheridan	$237,920	**$691,240**	$937,520

Table A.11b Carbon County asphalt roads recommended improvements by road

Road Name	Functional Class	Miles	Cost
Sage Creek	Major Collector	7.62	$709,085
Jack Creek Road	Major Collector	1.07	$171,040
Leavengood Lane	Minor Collector	0.38	$60,160
Saratoga/10 Mile/Ryan Park	Major Collector	0.94	$18,880
Elk Mountain - Medicine Bow	Major Collector	0.77	$15,340
Medicine Bow - McFadden	Minor Collector	0.06	$9,440
	TOTAL	10.83	$983,945

Table A.11c Carbon County asphalt roads recommended improvements by functional class and improvement activity

Maintenance Activity	Recommended Improvement Costs			
	Local	Minor Collector	Major Collector	TOTAL
Chip Seal	$0	$0	$127,420	$127,420
Slurry Seal	$0	$0	$68,635	$68,635
Thick Overlay - 3	$0	$69,600	$171,040	$240,640
Rehabilitation	$0	$0	$547,250	$547,250
TOTAL	$0	$69,600	$914,345	$983,945

Maintenance Activity	Miles Improved			
	Local	Minor Collector	Major Collector	TOTAL
Chip Seal	0.0	0.0	6.4	6.4
Slurry Seal	0.0	0.0	2.0	2.0
Thick Overlay - 3	0.0	0.4	1.1	1.5
Rehabilitation	0.0	0.0	1.0	1.0
TOTAL	0.0	0.4	10.4	10.8

Table A.11d Johnson County asphalt roads recommended improvements by road

Road Name	Functional Class	Miles	Cost
Trabing	Major Collector	13.71	$20,557,500
Irigaray	Major Collector	11.48	$14,532,600
TW	Major Collector	3.06	$4,585,500
Airport	Major Collector	1.59	$2,382,000
Tipperary	Major Collector	7.12	$1,138,400
Rock Creek	Minor Collector	5.03	$623,660
Monument	Minor Collector	3.23	$516,960
French Creek	Minor Collector	1.00	$159,360
Klondike	Minor Collector	0.85	$135,840
TTT	Minor Collector	0.53	$53,200
Robinson Lane	Local	0.30	$27,270
	TOTAL	47.89	$44,712,290

Table A.11e Johnson County asphalt roads recommended improvements by functional class and improvement activity

	Recommended Improvement Costs			
Maintenance Activity	Local	Minor Collector	Major Collector	TOTAL
Thin Overlay - 1½	$27,270	$354,300	$0	$381,570
Thick Overlay - 3	$0	$1,134,720	$1,460,000	$2,594,720
Reconstruction	$0	$0	$41,736,000	$41,736,000
TOTAL	$27,270	$1,489,020	$43,196,000	$44,712,290

	Miles Improved			
Maintenance Activity	Local	Minor Collector	Major Collector	TOTAL
Thin Overlay - 1½	0.30	3.54	0.00	3.85
Thick Overlay - 3	0.00	7.09	9.13	16.22
Reconstruction	0.00	0.00	27.82	27.82
TOTAL	0.30	10.64	36.95	47.9

Table A.11f Sheridan County asphalt roads recommended improvements by road

Road Name	Functional Class	Miles	Cost
Swaim	Minor Collector	1.487	$237,920
Beaver Creek	Minor Collector	0.743	$118,880
West Brundage Lane	Minor Collector	0.685	$109,600
Country Nite Club	Local	0.616	$92,400
Acme	Local	0.860	$77,400
Upper Road	Minor Collector	0.34	$55,040
	TOTAL	4.74	$691,240

Table A.11g Sheridan County asphalt roads recommended improvements by functional class and improvement activity

	Recommended Improvement Costs			
Maintenance Activity	Local	Minor Collector	Major Collector	TOTAL
Thin Overlay - 1½	$77,400	$0	$0	$77,400
Thick Overlay - 3	$92,400	$521,440	$0	$613,840
TOTAL	$169,800	$521,440	$0	$691,240

	Miles Improved			
Maintenance Activity	Local	Minor Collector	Major Collector	TOTAL
Thin Overlay - 1½	0.9	0.0	0.0	0.9
Thick Overlay - 3	0.6	3.3	0.0	3.9
TOTAL	1.5	3.3	0.0	4.7

A.12 ANNUAL GRAVEL ROADS CONSTRUCTION AND ROUTINE MAINTENANCE COSTS

Table A.12a Carbon County gravel roads annual construction and routine maintenance needs

	Resource	Local	Minor Collector	Major Collector	TOTAL
Plowing, Mowing and Spraying	$20,867	$126,341	$259,734	$131,313	$538,256
Drainage Maintenance	$13,564	$62,168	$69,216	$29,702	$174,649
Surface Maintenance	$24,415	$613,456	$1,391,332	$861,744	$2,890,947
MAINTENANCE	$58,845	$801,964	$1,720,282	$1,022,759	$3,603,851
Repairs	$0	$266,720	$520,872	$327,189	$1,114,781
Reconstruction	$0	$224,606	$561,587	$393,940	$1,180,134
CONSTRUCTION	$0	$491,326	$1,082,459	$721,129	$2,294,915
TOTAL	$58,845	$1,293,291	$2,802,741	$1,743,889	**$5,898,766**

Table A.12b Johnson County gravel roads annual construction and routine maintenance needs

	Resource	Local	Minor Collector	Major Collector	TOTAL
Plowing, Mowing and Spraying	$3,578	$74,860	$205,534	$40,788	$324,760
Drainage Maintenance	$2,326	$36,836	$54,772	$9,226	$103,159
Surface Maintenance	$4,186	$363,485	$1,100,995	$267,671	$1,736,337
MAINTENANCE	$10,090	$475,180	$1,361,301	$317,685	$2,164,256
Repairs	$0	$158,037	$412,179	$101,630	$671,846
Reconstruction	$0	$133,084	$444,398	$122,364	$699,845
CONSTRUCTION	$0	$291,121	$856,576	$223,994	$1,371,691
TOTAL	$10,090	$766,301	$2,217,877	$541,678	**$3,535,947**

Table A.12c Sheridan County gravel roads annual construction and routine maintenance needs

	Resource	Local	Minor Collector	Major Collector	TOTAL
Plowing, Mowing and Spraying	$7,077	$79,388	$198,800	$29,425	$314,690
Drainage Maintenance	$4,600	$39,064	$52,977	$6,656	$103,297
Surface Maintenance	$8,280	$385,474	$1,064,921	$193,103	$1,651,778
MAINTENANCE	$19,957	$503,926	$1,316,698	$229,184	$2,069,765
Repairs	$0	$167,597	$398,674	$73,318	$639,589
Reconstruction	$0	$141,135	$429,837	$88,276	$659,247
CONSTRUCTION	$0	$308,732	$828,511	$161,594	$1,298,836
TOTAL	$19,957	$812,658	$2,145,208	$390,778	**$3,368,602**

A.13 ANNUAL ASPHALT ROADS CONSTRUCTION AND ROUTINE MAINTENANCE COSTS

Table A.13a Carbon County annual asphalt roads construction and routine maintenance costs

	Local	Minor Collector	Major Collector	TOTALS
Drainage	$3,974	$10,850	$44,257	$59,081
Mowing, Spraying, and Plowing	$2,663	$12,789	$64,918	$80,370
Patching	$888	$2,489	$10,549	$13,925
Seals	$8,167	$27,652	$146,065	$181,883
Overlays	$10,652	$35,948	$173,114	$219,714
Major Improvements	$5,326	$47,354	$302,949	$355,629
TOTAL	$31,670	$137,081	$741,851	$910,602
MILES	5.9	13.8	54.1	73.8
Cost per Mile	$5,351	$9,915	$13,713	$12,332

Table A.13b Johnson County annual asphalt roads construction and routine maintenance costs

	Local	Minor Collector	Major Collector	TOTALS
Drainage	$2,290	$38,877	$42,341	$83,508
Mowing, Spraying, and Plowing	$1,535	$45,825	$62,107	$109,466
Patching	$512	$8,917	$10,092	$19,521
Seals	$4,706	$99,080	$139,741	$243,527
Overlays	$6,138	$128,804	$165,619	$300,561
Major Improvements	$3,069	$169,675	$289,834	$462,577
TOTAL	$18,248	$491,177	$709,735	$1,219,161
MILES	3.4	49.5	51.8	104.7
Cost per Mile	$5,351	$9,915	$13,713	$11,644

Table A.13c Sheridan County annual asphalt roads construction and routine maintenance costs

	Local	Minor Collector	Major Collector	TOTAL
Drainage	$3,492	$13,914	$7,798	$25,204
Mowing, Spraying, and Plowing	$2,340	$16,400	$11,438	$30,179
Patching	$780	$3,191	$1,859	$5,830
Seals	$7,177	$35,460	$25,736	$68,374
Overlays	$9,362	$46,098	$30,502	$85,962
Major Improvements	$4,681	$60,725	$53,379	$118,785
TOTAL	$27,833	$175,789	$130,713	$334,335
MILES	5.2	17.7	9.5	32.5
Cost per Mile	$5,351	$9,915	$13,713	$10,299

The costs for seals, which include fog seals, crack seals, chip seals, and slurry seals, may seem rather high. However, these are preventive maintenance activities. If one were to use lower values for seals, the cost of other treatments, particularly overlays and patching, should be increased. If asphalt roads do not receive adequate preventive maintenance, they will need to be overlaid more often, and they will deteriorate to the point where they need to be patched more often.

A.14 CULVERT RECOMMENDED IMPROVEMENTS

Table A.14a Carbon County recommended culvert improvements

	Repair Costs	Number Repaired	Replacement Costs	Number Replaced	Length Replaced	Cleaning Costs	Number Cleaned	Total Costs
≤18"	$17,250	115	$197,250	80	2,630	$44,350	284	$258,850
19" - 42"	$24,000	80	$97,100	28	971	$21,720	161	$142,820
43" - 59"	$650	2	$4,500	1	30	$240	2	$5,390
60" - 69"	$350	1	$0	0	0	$540	4	$890
≥70"	$0	0	$0	0	0	$0	0	$0
TOTAL	$42,250	198	$298,850	109	3,631	$66,850	451	$407,950

Table A.14b Johnson County recommended culvert improvements

	Repair Costs	Number Repaired	Replacement Costs	Number Replaced	Length Replaced	Cleaning Costs	Number Cleaned	Total Costs
≤18"	$31,650	211	$247,950	94	3,306	$43,600	367	$323,200
19" - 42"	$24,300	81	$145,200	29	1,452	$16,860	133	$186,360
43" - 59"	$4,225	13	$54,000	6	360	$2,560	17	$60,785
60" - 69"	$0	0	$7,000	1	35	$990	4	$7,990
70" - 84"	$1,600	4	$0	0	0	$700	4	$2,300
≥85"	$0	0	$0	0	0	$0	0	$0
TOTAL	$61,775	309	$454,150	130	5,153	$64,710	525	$580,635

Table A.14c Sheridan County recommended culvert improvements

	Repair Costs	Number Repaired	Replacement Costs	Number Replaced	Length Replaced	Cleaning Costs	Number Cleaned	Total Costs
≤18"	$36,450	243	$349,500	138	4,660	$68,400	515	$454,350
19" - 42"	$33,000	110	$159,800	35	1,598	$19,140	167	$211,940
43" - 59"	$3,900	12	$46,200	3	308	$800	7	$50,900
60" - 69"	$700	2	$0	0	0	$180	2	$880
70" - 84"	$2,400	6	$12,600	1	42	$1,700	8	$16,700
85" - 96"	$500	1	$0	0	0	$0	0	$500
97" - 119"	$0	0	$0	0	0	$0	0	$0
≥120"	$0	0	$0	0	0	$450	2	$450
TOTAL	$76,950	374	$568,100	177	6,608	$90,670	701	$735,720

A.15 ANNUAL CULVERT REPLACEMENT AND MAINTENANCE COSTS

Table A.15a Carbon County annual culvert replacement and maintenance costs

	Number	Length, ft	Annual Replacement Costs	Annual Repair Costs	Annual Cleaning Costs	Total Annual Costs
≤18"	688	25,498	$38,247	$5,160	$4,914	$48,321
19" - 42"	641	30,914	$61,828	$9,615	$5,494	$76,937
43" - 59"	64	4,158	$12,474	$1,040	$731	$14,245
60" - 69"	47	3,539	$14,156	$823	$604	$15,583
70" - 84"	28	2,493	$14,958	$560	$400	$15,918
85" - 96"	3	208	$1,664	$75	$51	$1,790
97" - 119"	6	630	$6,300	$225	$111	$6,636
≥120"	15	1,266	$18,990	$750	$321	$20,061
TOTAL	1,492	68,706	$168,617	$18,248	$12,629	$199,493

Table A.15b Johnson County annual culvert replacement and maintenance costs

	Number	Length, ft	Annual Replacement Costs	Annual Repair Costs	Annual Cleaning Costs	Total Annual Costs
≤18"	1,001	39,217	$58,826	$7,508	$7,150	$73,483
19" - 42"	557	25,597	$51,194	$8,355	$4,774	$64,323
43" - 59"	86	4,432	$13,296	$1,398	$983	$15,676
60" - 69"	19	792	$3,168	$333	$244	$3,745
70" - 84"	45	2,425	$14,550	$900	$643	$16,093
85" - 96"	9	453	$3,624	$225	$154	$4,003
97" - 119"	1	60	$600	$38	$19	$656
≥120"	3	194	$2,910	$150	$64	$3,124
TOTAL	1,721	73,170	$148,168	$18,905	$14,031	$181,104

Table A.15c Sheridan County annual culvert replacement and maintenance costs

	Number	Length, ft	Annual Replacement Costs	Annual Repair Costs	Annual Cleaning Costs	Total Annual Costs
≤18"	1,264	49,474	$74,211	$9,480	$9,029	$92,720
19" - 42"	610	28,458	$56,916	$9,150	$5,229	$71,295
43" - 59"	73	4,130	$12,390	$1,186	$834	$14,411
60" - 69"	39	2,203	$8,812	$683	$501	$9,996
70" - 84"	63	3,593	$21,558	$1,260	$900	$23,718
85" - 96"	14	961	$7,688	$350	$240	$8,278
97" - 119"	2	110	$1,100	$75	$37	$1,212
≥120"	17	1,013	$15,195	$850	$364	$16,409
TOTAL	2,082	89,942	$197,870	$23,034	$17,134	$238,038

A.16 IMPLEMENTATION RECOMMENDATIONS

A.16.1 Implementation Issues

There are three primary aspects to operating any GIS–based asset management program: data collection, data storage, and analysis that results in report and map generation. To establish a GIS–based asset management program, all three of these functions must be considered. As described above, many counties already have a person, and in some cases a department, that can handle the data storage aspects of asset management. Once a well-designed GIS system is in place, it is relatively easy to retrieve information from the GIS system. Most people who are comfortable with software packages, such as spreadsheets or databases, could easily be trained to generate reports or maps with the GIS system. A skilled GIS person could build software that could generate routine reports. Thus, data storage and management demands a skilled GIS person; report generation is a relatively easy task for a computer–literate individual with relatively little training; data collection is the greatest hurdle to be overcome when implementing a GIS–based asset management program since it should be performed on an ongoing basis by those whose primary function is not collecting data or working with computers.

A.16.1.1 Software Development

A major task outside operating the asset management system is building the system. This requires software development. There are a number of commercial software packages out there, though none have been identified that would do precisely what needs to be done. There are also packages designed to track a county's expenditures that, at least in theory, could be tied into a GIS–based database. Again, no packages that fulfill this need have been identified.

Identifying potential commercially available software should be part of any implementation package. Unfortunately, it may be difficult to assess how well a given piece of software will work, how compatible it is with other software, and, most difficult and important, how good the software support is. The alternative to purchasing software is to contract to have software developed, which also raises the issue of support for any developed software.

A.16.1.2 Data Collection

Data collection is vital to the success of an asset management program. If a database is not kept up–to–date, its value will quickly be lost. It does not matter what the condition of a road and bridge network was two, five, or 10 years ago. What matters is the current condition. This can only be achieved if there is a system in place to keep the database current. This can only be achieved with an ongoing method of updating the information in the GIS database.

While it is possible to use outside entities to collect data for a county's road and bridge department, it is the employees of the department that have the on–the–ground knowledge to properly update the database's information.

A.16.1.3 Integration of Existing Data

An additional issue is how to convert current GIS or non-GIS-based data into a format compatible with a GIS-based asset management system. While this would probably need to be handled on a case-by-case basis, there are several alternative approaches. The easy approach is to re-collect any data previously collected. Depending on the quality and quantity of any existing data, this may be the best approach. However, if a county has a significant amount of data that would be expensive to re-collect, this may not be the best option. The tricky part when converting data will be assigning a geographic location to data that are in, for example, a spreadsheet or database. Best estimates might be made, based on mileages or aerial photos, and locations might be changed on the ground when global positioning system (GPS) equipment becomes available for data collection and updating.

A.16.1.4 Cost Tracking

Though not directly a part of asset management, without cost tracking, the effectiveness of an asset management system will be greatly impaired. If the costs of performing specific maintenance or construction activities are not known, accurate economic decisions cannot be made as part of an asset management system. Accurate cost tracking provides vital inputs for an asset management system.

In an ideal world, all expenses could be traced back to the exact section of road where expenses are incurred. Currently, the technology to perform these functions is not, to the best of the author's knowledge, available. In other words, software is not available that will allow entry of maintenance data directly tied to a given road section’s location. Technologies such as GPS transmitters on heavy equipment might automate this process, though information about the operations being performed might still need to be entered by those performing work. For example, the operator might have to tell the computer whether shoulders are being pulled or the top is receiving skim maintenance. Until such technology is readily available, alternatives should be sought. Without some information on where money is being spent, it is difficult to improve efficiencies.

Some means of tracking expenses as they are spent on each road segment as described in section A.16.2.1 below is needed. The use of a commercial cost tracking software along with maps of each segment as defined in the asset management system is recommended. Generating maps with labeled sections, perhaps overlaid with aerial photos, should be provided to maintenance and construction crews so they may report the segment(s) they have worked on and the expenses incurred or activities performed on those segments.

A.16.2 DATE COLLECTION AND ROAD RATING

A.16.2.1 Road Sections and Segments

The logistics of this project dictated that students hired to perform the evaluations also had to divide each road into smaller sections for analytical purposes. Without the benefit of hiring individuals with extensive experience with roads, it was decided that each road should be broken into one–mile segments. This was the best solution available at the time. However, if more experienced individuals were available to establish road segments, they could break roads into more logical segments, rather than simply ending each segment after one mile. The overall goal of splitting roads into analytical units should be to make each segment a fairly homogeneous unit with limited variability. A drawback to this approach is that one cannot know the approximate mileage along a road simply by counting segments. A method should be established within the GIS software to easily determine the starting and ending mileages of these segments with variable lengths. The following list contains some criteria that might be used to divide roads into segments:

- *Intersections, Approaches, and Traffic Volumes*: Often, traffic volumes will change significantly before and after an intersection. For example, a side road serving a subdivision would add significantly to the car traffic on a road; an approach that serves a gravel pit would significantly change the truck traffic. Beginning and ending segments at significant intersections and approaches would make them more homogeneous.
- *Construction, Maintenance, and Materials*: Variability in how roads are built and maintained will significantly affect a road's performance. An obvious reflection of different construction practices would be the top width of the road, though other factors, such as material thicknesses, gravel properties, and drainage properties, will also affect a road's performance. Splitting a road into segments where different construction or maintenance practices have been used will help to reduce variability within a segment.
- *Alignment, Terrain, Drainage, and Soil Types*: When a road traverses from one geographically distinct area to another, its performance, safety, and durability may change significantly. Some roads are perfectly straight, following a section line between two pastures. Others wind their way through hilly or mountainous terrain, going wherever the lay of the land allowed construction of a serviceable road. The speed of the traveling public changes as the alignment changes. When a road goes from a stable, sandy subgrade to a subgrade with substantial clays, the road's performance will change. When a road runs adjacent to an irrigation ditch, its properties may be different from a similar section without an irrigation ditch next to it. These geographic factors and more should be considered when splitting a road into segments for analytical purposes.

A.16.2.2 Classification of Gravel and Asphalt Roads

In this pilot study, all county roads were classified as either gravel or asphalt. The PASER road rating system has five manuals devoted to rating roads classified as: unimproved, gravel, seal coat, asphalt, and concrete. In this study, unimproved and gravel roads were rated using the same criteria; similarly, asphalt, seal coat, and concrete roads were rated similarly. It would make more sense to have rating systems broken down into the additional categories, rather than just two. Defining roads as described below would make ratings more appropriate and consistent.

- *Unimproved/Earth/Dirt Roads*: Roads and two tracks on county systems that have surfaces made of native soils would be classified as dirt or earth roads. There is a distinction between dirt roads and unimproved roads. Dirt roads are those that are not surfaced with imported gravel, while unimproved roads generally lack drainage provisions and structures. Roads may be improved dirt roads or they may be unimproved gravel roads. A single criterion should be used to discriminate between these possibilities. Since drainage should always be rated, it makes more sense to refer to dirt or earth roads, with the deciding criterion being the surfacing materials, rather than whether the drainage has been improved. If the surfacing is made of native materials, it is not a gravel road; it is an earth or dirt road. Still, issues may arise when a road has had gravel applied in the past but the gravel has become mixed with native soil to the point where its properties are essentially those of the native soil. When the surfacing material's properties are essentially those of the native soil, the road should be considered an earth or dirt road.

- *Gravel Roads*: Roads that are surfaced with imported gravel are considered gravel roads. The distinction between gravel and earth roads is discussed above. The imported gravel may include reclaimed asphalt pavement (RAP), which might make one think it should be considered an asphalt road. The distinction between gravel and seal coat roads should be made based on an assessment of whether the road's surface can be reshaped with a motor grader. Unfortunately some surface treatments, such as dust suppressants, may make it undesirable to frequently rework the road surface. The deciding factor is not whether the surface is regularly shaped and maintained, but whether it can be maintained when the surface becomes excessively rough.

  Another type of road classification, a *stabilized gravel road*, might be desirable for roads that have a stabilized surface using a product such as magnesium chloride. However this is a problematic issue since a gravel road classified as stabilized might revert to a conventional gravel road if the dust suppressant or other stabilizer is not reapplied in a timely manner. In some cases, a dust suppressant may be used for a relatively short distance in front of a residence then discontinued away from the residence. Perhaps there should be a check box asking whether dust suppressant or stabilizer has been applied to a segment of a gravel road; if it has, the percentage of the road to which it has been applied could be estimated or measured and its current effectiveness could be noted. The effectiveness of the surface crust in shedding water and reducing dust could be assessed or estimated. Additionally, when a suppressant or stabilizer is applied, the amount and type of dust suppressant or stabilizer should be recorded along with the date when it was applied. This, along with the typical gravel road ratings of washboards, potholes, and ruts, could provide useful information about the effectiveness of a stabilizer or suppressant.
- *Seal Coat Roads*: Roads that do not have a layer of hot mix asphalt but have a hard, asphaltic surface provided by, for example, a chip seal or fog seal, should be considered a seal coat road if they are too hard and chunky to be successfully reshaped or smoothed with a motor grader. Such roads may deteriorate with time to the point where their surface is completely disintegrated and cannot be maintained with a motor grader. Such deterioration leads to a dilemma similar to the loss of gravel into a subgrade, changing a gravel road into a dirt road. Once a seal coat road has been reshaped with a motor grader, its classification should change to gravel.
- *Asphalt Roads*: Roads that have been surfaced with one or more lifts of hot mix asphalt should be considered asphalt roads, regardless of whether or not they have had a seal coat applied. Concrete roads overlaid with hot mix asphalt should also be considered asphalt roads.
- *Concrete Roads*: Roads with a portland cement concrete surface should be considered concrete roads. As with the discrimination between seal coat and gravel roads, a cement–stabilized road should be considered a concrete road if it cannot be reshaped with a motor grader; conversely, it should be considered a gravel road, perhaps a stabilized gravel road, if it can be reshaped with a motor grader.

It may at times be difficult to make these discriminations, but for the vast majority of roads, it should be easy to assign them into one of these categories. Going with fewer categories may create confusion and inconsistencies. An earth road will be maintained very differently from a gravel road; seal coat roads, though they may appear to be asphalt roads, perform differently and require different maintenance operations from roads with a layer of hot mix asphalt. In spite of these difficulties, it should be possible to split roads into these categories to accurately assess and predict their long-term performance.

A.16.2.3 Culvert Placement

Culverts were rated according to their condition and cleanliness. A third, and perhaps more important, consideration is whether they are in the correct geometric configuration. Are they long enough? Do they have enough grade? Do the inlets and outlets constitute a safety hazard within the clear zone? Are the inlets and outlets at the proper elevation relative to the ditches they connect? Are the inlets and outlets properly configured to minimize scour? These issues were deemed too complex for the data collectors to successfully assess, but more experienced evaluators should be able to rate these aspects of culverts. It is often in response to such geometric issues that culvert work becomes necessary.

A.16.2.4 Sign Retroreflectivity

Often, road signs are unnecessary during the day since drivers can see the hazard that the sign is warning them about. Curves are easy to spot when the sun is out, but at night we may not be able to see a curve in the road until it's too late unless a sign warns us. Retroreflectivity is the ability of a sign's sheeting material to reflect light from the vehicles headlights back to the driver's eyes. Evaluating signs for retroreflectivity is probably the most important factor in a warning sign's performance; as such, it should be included in the sign portion of any asset management system.

A.16.2.5 Other Features to Be Included

Additional features that might be tracked by an asset management system are as varied and complex as the roads themselves. Right-of-way and easements, approach permits, utilities, fences, roadway geometry and safety, guardrails, delineators, snow fences, bridge conditions, hydrology, and crash data are some of the features that might be included in a comprehensive asset management system beyond those that are described in this report.

A.16.2.6 Data Collection and Training

Data collection training would address those features that are to be collected in a standardized manner. Such classes could be taught in modules; the following list of topics (in **bold** below) is a partial list of modules that are available or could be developed, along with specific topics within each module:

- ***Currently developed by T^2***
  - **Gravel Road Surfaces**
    - Geometry
      - Top width
      - Crown
    - Overall condition
    - Drainage
    - Distresses
      - Potholes
      - Rutting
      - Washboards
      - Dust
      - Loose aggregate

- Gravel quantity
- Gravel quality

- **Asphalt Road Surfaces**
  - Geometry
    - Top width
    - Crown
  - Overall condition
  - Drainage
  - Distresses
    - Potholes
    - Rutting
    - Aging cracks
    - Fatigue cracks
    - Patching
    - Distortion
    - Polishing
    - Flushing
    - Raveling
- **Culvert evaluation**
  - Geometry
    - Diameter/height and width
    - Length
  - Condition
  - Flow/cleanliness
- **Sign evaluation**
  - Geometry
    - Panel dimensions
    - Post size
  - Sheeting condition
    - Damage
    - Retroreflectivity
  - Panel condition
  - Post condition
- **Cattleguard evaluation**
  - Geometry
    - Width and length
  - Grate condition and type
  - Base condition and type
  - Approach condition
  - Wingfence condition
- **Approaches**
  - Type
    - Residential
    - Field
    - Drilling
    - Mining
    - Construction
  - Gate type

- ***Developable by T^2***

- **Unimproved/Earth/Dirt Roads**
  - Geometry
    - Top width
    - Crown
  - Overall condition
  - Profile and ride
  - Drainage
  - Surface material
  - Access
  - Distresses
    - Ruts
    - Potholes
    - Rocks and roots
    - Washboards
- **Sealcoat Roads**
  - Geometry
    - Top width
    - Crown
  - Overall condition
  - Drainage
  - Distresses
    - Wear and flushing
    - Loss of surface
    - Edge cracking
    - Fatigue cracking
    - Age cracking
    - Patching
    - Potholes
- **Concrete Roads**
  - Surface defects
    - Wear and polishing
    - Map cracking
    - Pop–outs
    - Scaling
    - Shallow reinforcing
    - Spalling
  - Joints
    - Longitudinal joints
    - Transverse joints
    - Transverse slab cracks
  - Cracking
    - D–cracking
    - Corner cracking
    - Meander cracks
  - Pavement deformation
    - Blowups
    - Faulting
    - Pavement settling or heave
    - Utility repairs, patches and potholes

        - Manhole and inlet cracking
        - Curb or shoulder deformation
- **Stabilized Gravel Roads**
    - *All features rated for gravel roads*
    - Surface crust and tightness
    - Slipperiness when wet
- **Culvert evaluation**
    - Placement
        - Grade
        - Safety hazard within clear zone
        - Inlet and outlet elevations relative to ditch line
        - Scour potential
    - Appropriate length
- **Hydrology**
- **Approaches**
    - Geometry
        - Width
        - Radius
        - Length
- **Utilities**
- **Fencing**
- **Guardrails**
- **Delineators**
- **Geometry and Safety**
    - Intersections
    - Vertical curves and sight distance
    - Horizontal curves and sight distance
    - Clear zones
        - Obstacles
        - Slope
        - Width
    - Signs and delineators
    - Surface condition
    - Speed
    - Guardrails
- **Bridge conditions**