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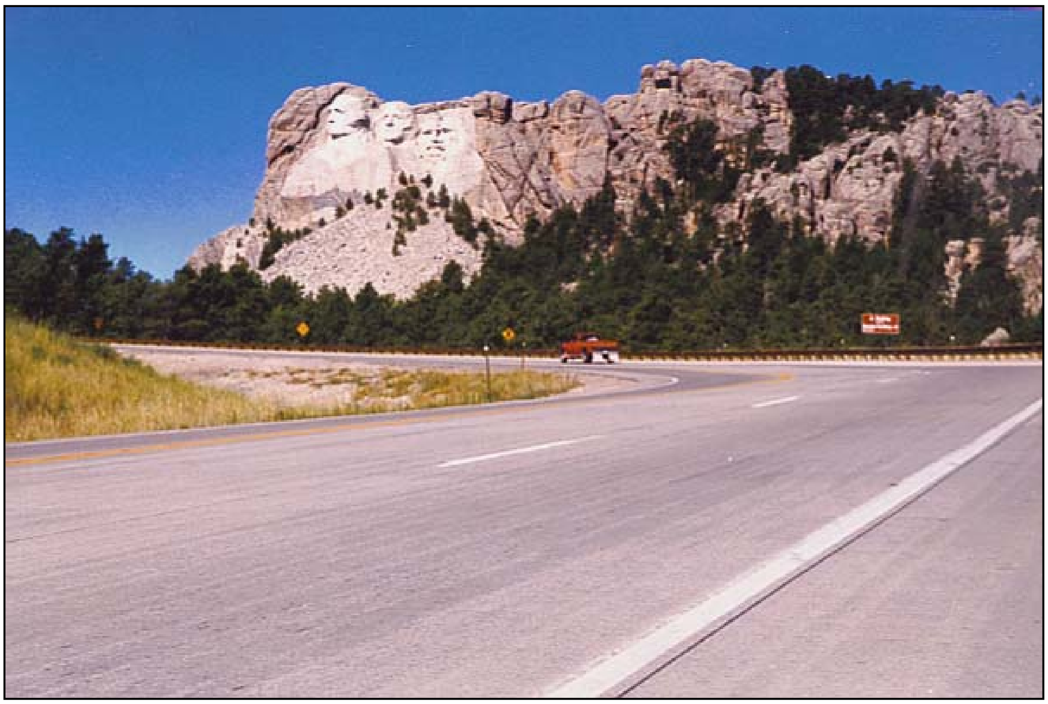

Local Road Surfacing Criteria

Study SD2002-10
Final Report

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15. Supplementary Notes

A technical brief that provides details on the methodologies used to evaluate road sections is published as SD2002-10-TB. A software tool and users guide (SD2002-10-UG), developed as part of this project, provides an advanced tool for making local road surfacing decisions and is available through the sponsoring agency.

16. Abstract

On a daily basis, local road agencies in South Dakota face the question of how to cost-effectively maintain low-volume roads. Specifically, decision makers are faced with the challenge of determining when it is most economical to maintain, upgrade, or downgrade a road's existing surface.

In order to assist decision makers with these types of decisions, the South Dakota Department of Transportation (SDDOT) initiated a research study in 2002 to investigate surfacing criteria for low-volume roads (LVR). The overall objective of this research study is to create a process that allows the user to compare the costs associated with different types of roads to provide assistance in deciding which surface type (hot-mix asphalt [HMA], blotter, gravel, or stabilized gravel) is most economical under a specific set of circumstances. In addition to incorporating economic factors into the analysis, the process also allows the user to consider other non-economic factors that are more subjective and difficult to quantify, such as political factors, growth rates, housing concentration, mail routes, and industry/truck traffic. The process used during this study is flexible enough to allow users to consider any combination of agency costs incurred by the agency for maintaining its roads, non-agency (user) cost factors such as vehicle operating costs or crash potential, and non-economic factors such as politics and housing densities.

The underlying methodology developed during this project for making road surface type decisions is based upon life-cycle cost analysis (LCCA) techniques that focus on selecting the most cost-effective road surface to meet a specific need. The methodology was created using agency cost and user cost models that were developed based upon specific road section information supplied by various local agencies in South Dakota, average daily traffic (ADT) and crash occurrence information supplied by the SDDOT, information obtained through a literature search, and input from members of the Technical Panel. The primary deliverables for this study include a Technical Brief that summarizes the manual procedure for determining the appropriate surface type for a road section based upon the average conditions, a software tool that allows the user to analyze economic and non-economic factors at specific locations to determine the appropriate surface type.

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Low-volume roads, surfacing criteria, life-cycle cost analysis, South Dakota, software tools	No restrictions. This document is available to the public from the sponsoring agency.

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1.0 EXECUTIVE SUMMARY

On a daily basis, local road agencies in South Dakota face the challenge of how to cost-effectively maintain low-volume roads. Specifically, decision makers are faced with the challenge of determining when it is most economical to maintain, upgrade, or downgrade a road's existing surface.

In order to assist decision makers facing these types of challenges, the South Dakota Department of Transportation (SDDOT) initiated a research study in 2002 to investigate surfacing criteria for low-volume roads (LVR). The overall objective of this research study is to create a process that allows the user to compare the costs associated with different types of roads in order to provide assistance in deciding which surface type (hot-mix asphalt [HMA], blotter, gravel, or stabilized gravel) is most economical under a specific set of circumstances. In addition to incorporating economic factors into the analysis, the process also allows the user to consider non-economic factors that are more subjective and difficult to quantify, such as politics, growth rates, housing concentration, mail routes, and industry/truck traffic. The process developed during this study is flexible enough to allow users to consider any combination of costs incurred by the agency for maintaining its roads, non-agency (user) cost factors (such as vehicle operating costs or crash potential), and non-economic factors (such as politics and housing densities).

The specific objectives for this study are as follows:

1. To model agency costs as a function of surfacing type and other potentially significant variables, such as materials availability, structural condition, traffic, and environmental factors.

2. To model certain user costs as a function of surfacing type and other potentially significant variables, such as materials availability, structural condition, traffic, and environmental factors.

3. To develop practical methodologies for using agency and user cost models to determine when to maintain, upgrade, or downgrade road surface types on local road segments.

Each of these objectives was achieved during the course of this project. The agency cost and user cost models were developed using specific road section information supplied by various local agencies in South Dakota, average daily traffic (ADT) and crash occurrence information supplied by the SDDOT, information obtained through a literature search, and input from members of the Technical Panel. The primary deliverables for this study include a *Technical Brief* that summarizes the manual procedure for determining the appropriate surface type for a road section based upon the average conditions, a software tool that allows the user to analyze economic and non-economic factors at specific locations to determine the appropriate surface type, and Train-the-Trainer materials to explain the use of the manual procedure and automated software.

The underlying methodology developed during this project for making road surface type decisions is based upon life-cycle cost analysis (LCCA) techniques that focus on selecting the most cost-effective road surface to meet a specific need. In life-cycle costing, the term agency cost is used to define the funds expended by the local agency to build and maintain the given roadway. In addition to agency costs, a life-cycle cost analysis often considers user costs. User costs include the vehicle operating, crash, and delay costs incurred by the users of a facility. In a life-cycle cost analysis, various combinations of user costs may be incorporated into the analysis depending upon the desires of the agency. For this study, a decision was made to include only the vehicle operating and crash components of the user costs in the life-cycle cost analysis and to make them available as an optional feature of the surface type selection process.

In order to calibrate the methodology to local agencies in South Dakota, all counties in the state were asked to provide data related to specific road sections in their county. An attempt was made to collect data for all road surface types so that a full range of ADT, truck percentage levels, terrains, and subgrade types were represented in the development of the models. A total of twenty-three of the sixty-six counties in the State participated in the study.

The counties that were interested in participating in the study were provided with survey forms requesting specific section information including initial cost, maintenance costs and frequency, and other pertinent information that was needed in developing the agency cost models. In order to develop the user cost models, accident data and ADT information for each pavement section included in the study was provided by the SDDOT.

After all the necessary information was collected from the counties, a life-cycle cost analysis was conducted on each pavement section using a 20-year analysis period and a 3.5 percent discount rate to determine the present worth value. The life-cycle cost analysis was conducted using the recommendations provided by the Federal Highway Administration (FHWA) in an interim bulletin on this topic (Walls and Smith 1998). The life-cycle cost calculations for the vehicle operating costs are based on industry averages for the cost of operating vehicles on paved surfaces that are adjusted based on factors that include surface type, speed, vehicle type, and road grade.

The results of the life-cycle cost analysis for each section were combined for use in model development to determine whether statistically significant relationships existed between variables that included surface type, ADT, terrain type, subgrade type, and truck traffic level. The final results show that ADT is statistically significant in calculating agency and vehicle operating costs on HMA, blotter, and gravel roads. This allowed models for agency and vehicle operating cost to be developed using ADT as the independent variable. Due to the random nature of factors that affect crash occurrences, none of the variables tested provided a statistically significant way of predicting crash costs. Therefore, crash costs were grouped into various categories based on anticipated crash levels. The crash costs are based on average industry costs for different types of accidents that were adjusted using the crash data provided by the SDDOT.

The resulting models were then incorporated into a practical methodology that uses agency and user cost models to determine when to maintain, upgrade, or downgrade road surface types on local road segments. The methodology can be applied by local agencies using either a manual or an automated process. The manual process is documented in the *Technical Brief* and the automated process is available as a spreadsheet tool, which includes a stand-alone *User's Guide*.

The *Technical Brief* outlines the manual application of the methodology developed under this project. It outlines a step-by-step procedure for making road surface type decisions between different surface materials (hot-mix asphalt [HMA], blotter, and gravel) on low volume roadways. The approach outlined in the *Technical Brief* is flexible enough to allow users to consider any combination of those costs actually incurred by the agency for maintaining their roads, non-agency cost factors such as vehicle operating costs or crash potential, or non-economic factors such as politics or housing densities. Whatever considerations are included in the analysis, the methodology presented in the *Technical Brief* provides a practical tool to assist agencies with decisions about the most cost-effective road surface type to be used in various situations. The *Technical Brief* will be distributed through both the South Dakota Local Transportation Assistance Program (SDLTAP) and the South Dakota Office of Local Government Assistance (LGA). Train-the-Trainer materials are also provided to assist these agencies with transferring the technology developed during this project.

In addition to the development of the *Technical Brief*, a computerized spreadsheet decision tool has been developed in Excel that provides the user with an automated approach to applying the methodology to assist with decisions about which surface type is most economical under a specific set of circumstances. The tool provides a process for the user to consider the same factors as the manual procedure: agency costs, user costs in the form of crash and vehicle operating costs, and non-economic factors. The software tool provides a more detailed analysis for the user in comparison to the procedure summarized in the *Technical Brief.* Advanced user functions are also available for the sophisticated user who may want to alter the program's default values.

Besides producing several useful products for the SDDOT and the local agencies within the State, several recommendations emerged from this project. These include a recommendation to test the methodology on several projects before full distribution to all counties within the State. Once the methodology has been tested, a recommendation is included to distribute the products developed during the study and provide training to local agencies within the State on the application of these tools. Copies of the *User's Guide* for the automated software tool should be distributed to local agencies along with the tool to facilitate its use. A recommendation is also included to review the default models in the future as costs and treatment policies in South Dakota change.

2.0 PROBLEM STATEMENT

South Dakota's transportation network includes over 83,000 miles of roads, of which about 10 percent are state-controlled and 3 percent are federal routes. That leaves about 72,000 miles in the care of counties, townships, and municipalities, and most of these are considered to be LVR, defined by AASHTO as carrying less than 400 vehicles per day (AASHTO 1993). These roads are primarily either bituminous- or gravel-surfaced, with the more rural and lower volume roads typically being gravel-surfaced and the more heavily traveled roads being bituminous-surfaced. South Dakota’s bituminous-surfaced roads have either some type of bituminous surface treatment (often referred to as a “blotter” surface) or an HMA mat.

On a daily basis, local road agencies in South Dakota face the challenge of how to cost-effectively maintain LVR. Specifically, decision makers are faced with the challenge of determining when it is most economical to maintain, upgrade, or downgrade a road’s existing surface. The issues facing the local agencies that are responsible for these roads are complex. They include decisions about:

- In general, whether and how to maintain the road.
- When gravel roads should be converted to bituminous-surfaced roads.
- When bituminous-surfaced roads should be converted to gravel roads

On higher volume paved roads in South Dakota, decision-making has evolved into a fairly sophisticated process that is done under the framework of a pavement management system (PMS). Pavement management involves the establishment of a database that stores key information about all of the roads for which the agency is responsible, including information about pavement condition that is updated annually. Inventory information and performance data are used to develop models that predict how the various types of pavements in South Dakota are expected to perform, and those results in turn can be used to identify candidate projects for South Dakota’s Surface Transportation Improvement Program (STIP).

On LVR, the decision-making process is very different. Most local governmental units do not use the same decision tools to help them with the maintenance and rehabilitation decisions made in conjunction with a PMS. Maintenance and rehabilitation decisions about how to maintain roads are primarily made based on economic factors but less money is available for the maintenance of low-volume roads as there is for high volume roads. Project selection may be based on primary factors that include overall traffic volumes, truck volumes, and surface type and condition, and secondary factors such as terrain, support conditions, availability of materials, and subsequent maintenance costs. But due to funding constraints, projects that are in poor condition are frequently forced to be addressed with inadequate, or stop-gap, treatments.

The traveling public’s concerns about road conditions may also be economic, but tend to reflect personal rather than public costs. The public’s economic concerns are usually referred to as users’ costs, and include vehicle operating costs, user delay costs, and crash costs. Maintaining accessibility is also a primary concern of the public, and can override economic concerns at the individual level; in other words, the traveling public may be able to understand and support economic-based decisions as long as they include maintaining acceptable access to their own homes.

In South Dakota, as elsewhere, ever tighter financial constraints combined with rapidly changing demographics place constant pressure on local agencies to make wise decisions regarding their LVR. This decision-making process can be supported by applying a rational methodology that considers both the factors that are important to the local agency and the factors that are important to users. In addition, the consideration of other factors (such as politics, growth rates, housing concentration/dust control needs, mail routes, and industry/truck traffic) must also be considered in the process. Ultimately, such a methodology, when customized to address the types of pavements, traffic, and other concerns that are local to South Dakota, would be very useful as a decision-support tool for local road surfacing decisions.

It is clear that a methodology is needed to assist local agencies in assessing the economic tradeoffs between maintaining existing highway surfaces and upgrading or downgrading surface type to match users' needs and expectations. Furthermore, guidance is needed on the application of the methodology to typical conditions in the State.

3.0 OBJECTIVES

The objectives of this research project, as stated in the Request for Proposals (RFP), are as follows:

1. To model agency costs as a function of surfacing type and other potentially significant variables, such as materials availability, structural condition, traffic, and environmental factors.

2. To model certain user costs as a function of surfacing type and other potentially significant variables, such as materials availability, structural condition, traffic, and environmental factors.

3. To develop practical methodologies for using agency and user cost models to determine when to maintain, upgrade, or downgrade road surface types on local road segments.

Each of these objectives was addressed during the course of this project. A brief description of how the objectives were met follows.

3.1 Model Agency Costs as a Function of Surfacing Type and Other Significant Variables

A thorough literature review was conducted regarding the guidelines for managing, rehabilitating, and paving low-volume roads. During the literature review, special attention focused on how agency life-cycle costs should be modeled for the local road surface types (HMA, blotter, gravel, and stabilized gravel) used in South Dakota. The fundamentals presented in the FHWA interim bulletin regarding life-cycle cost analysis by Walls and Smith (1998) were used to determine the agency cost considerations for a 20-year analysis period.

Agency life-cycle costs were determined for all roadway sections for which data was collected. It was determined that ADT was statistically significant at predicting agency costs for all surface types except stabilized gravel. Therefore, agency costs for HMA, blotter, and gravel roads were modeled as a function of ADT. Other guidelines were established for recommendations of stabilized gravel as an appropriate surface type.

3.2 Model User Costs as a Function of Surfacing Type and Other Significant Variables

Based on the information obtained from the literature review, the knowledge and expertise of the project team, and guidance provided by the SDDOT Technical Panel, analytical methods were developed for modeling the selected user costs, which include vehicle operating costs and crash costs. Life-cycle costs for vehicle operating costs were determined using Winfrey's (1969) approach that considers surface type, speed, vehicle type, and road grade in determining the operating costs for all vehicles utilizing the road. The vehicle operating costs are based on industry averages for the cost of operating vehicles on paved surfaces that are adjusted based upon the different factors. Crash occurrences over a 10-year period were provided by the SDDOT for each roadway section. Yearly crash rates were calculated and multiplied by standard FHWA crash costs that were adjusted to the analysis year.

Once the crash and vehicle operating costs were determined for each roadway section, statistical tests were conducted to determine if any roadway variables were significant in predicting the user costs. ADT was determined to be statistically significant at predicting the vehicle operating cost for all roadway types, so models were created that predict vehicle operating costs based upon ADT levels. During the statistical tests, none of the tested variables were determined to be significant at predicting the crash costs. In order to model crash costs, crashes were classified into various categories and costs were associated with each category. A table was created to link potential crash levels with the associated average costs of each.

3.3 Develop Practical Methodologies for Using Agency and User Cost Models to Determine when to Maintain, Upgrade, or Downgrade Road Surface Types

The emphasis of the study was to develop a practical methodology for using the agency and user cost models to recommend when to maintain, upgrade, or downgrade road surface types on local roads. Using the agency and user cost models, a methodology was developed to consider both economic and non-economic factors in the surface type decision process. A description of the manual, step-by-step procedure for making low-volume road surface type decisions is presented in a stand-alone *Technical Brief*. The approach outlined in this document is flexible enough to allow users to consider any combination of costs actually incurred by the agency for maintaining their roads, non-agency cost factors (such as vehicle operating costs or crash potential), and non-economic factors (such as politics and housing density). In addition to the *Technical Brief*, an automated spreadsheet tool was developed to enable decision makers to customize the methodology to reflect conditions specific to their own agencies. Whatever analysis tool is utilized in determining the proper road surface type, the methodology incorporated into the *Technical Brief* and the spreadsheet provides a practical tool to assist agencies with decisions about the most cost-effective road surface type to be used in various situations.

4.0 TASK DESCRIPTION

The Technical Panel for this project established thirteen tasks which, when successfully completed, would meet the project's objectives. The project tasks are repeated here, and are followed by an explanation of how the project team accomplished each task.

Task 1. Meet with the Project's Technical Panel to Review Project Scope and Work Plan

Members of the Technical Panel met with the Principal Investigator on November 13, 2002, to discuss the project approach and the proposed methodology. The Principal Investigator presented an overview of the project objectives and the tasks to be conducted during the project. In addition, she presented a summary of the results of the literature review and discussed the recommendations for modeling agency and user costs with the panel. The meeting concluded with the identification of local agencies that could potentially provide the data needed to calibrate the models.

During the meeting, a few minor changes were made to the work plan. In addition to making the presentation to the SDDOT Research Review Board at the conclusion of the project, a decision was made to eliminate the requirement to have the project team present a session to the South Dakota Association of County Commissioners, South Dakota Association of Highway Superintendents, and the South Dakota Association of Towns and Townships due to problems coordinating the meetings. Instead, it was decided that the project team members would produce the Train-the-Trainer materials and deliver them at the conclusion of the project as a deliverable. Also during the meeting, APTech agreed to provide the SDDOT with some information on the project results for use at the annual meeting of the Association of Counties expected to be held during the first week of October 2003, and a decision was made to distribute the *Technical Brief* through both the SDLTAP and the LGA.

Task 2. Review Literature Pertaining to Selection of Rural Road Surfacing Type on the Basis of Economic and Other Criteria

The draft results of the literature review were completed and the results were presented to the Technical Panel at the kick-off meeting. Two especially relevant studies are *Economic Evaluation of Pavement Design Alternatives for Low-Volume Roads,* by David Luhr and Frank McCullough (1983), and *North Dakota Gravel Road Management: Alternative Strategies,* by Smadi et al. (1999). Luhr and McCullough used an economic analysis of agency and user costs to compare different surfacing types for different traffic volumes, and developed recommendations for the use of the optimal surface type based upon ranges of equivalent single axle loads (ESALs). Smadi et al. presented a case study illustrating the use of an economic analysis of the feasibility of paving gravel roads under various traffic levels.

In addition to these sources, work by the FHWA and Minnesota Department of Transportation (MnDOT) were helpful. The FHWA interim bulletin on LCCA by Walls and Smith (1998), for example, provided recommendations for the conduct of the LCCA. In addition, a study for MnDOT determined that typical ADT levels of 100 to 200 vehicles per day (vpd) represented the traffic level at which surfacing choices would switch from gravel to asphalt surfaced. Many other studies provided insights for the research team on how to approach the project methodology. The results of this literature review are summarized and included in Appendix A.

Task 3. Propose, for the Approval of the Project's Technical Panel, Analytical Methods for Relating Initial and Annualized Life-Cycle Construction and Maintenance Costs to Surfacing Type and Other Factors such as Traffic Volume, Truck Traffic Volume, Terrain, Subgrade Soil Type, Materials Availability, Climatic Conditions, and Other Environmental Variables

A proposed methodology was presented to, and accepted by, the Technical Panel at the kick-off meeting. Four surface types are considered in the study: HMA, blotter, gravel, and stabilized gravel. The basis of the study is to compare the life-cycle cost of each surface type based upon agency costs, user costs (vehicle operating costs and crash costs), and other non-economic factors (political factors, growth rates, housing concentration, mail routes, and industry/truck traffic). The analysis period utilized for the study is 20 years with a discount rate of 3.5 percent.

Several traffic categories (less than 125 vpd, 125 to 250 vpd, 250 to 400 vpd, and greater than 400 vpd), terrain types (flat, rolling, and mountainous), subgrade strengths (poor [has spring load limits] and good [has no spring load limits]), and truck traffic levels (low [less than 10 percent of traffic] and high [greater than or equal to10 percent of traffic]) were identified as data elements that might support the methodology. The Technical Panel approved the use of these data element ranges for inclusion in the study. Therefore, these data elements were included on the data collection forms used to request data from the counties.

Task 4. Propose, for the Approval of the Project's Technical Panel, Analytical Methods for Relating Select User Costs – such as Vehicle Wear and Crash Costs – to Surfacing Type and Other Factors such as Traffic Volume, Truck Traffic Volume, Terrain, Subgrade Soil Type, Materials Availability, Climatic Conditions, and Other Environmental Variables

An approach for the consideration of crash costs and vehicle operating costs was proposed to, and accepted by, the Technical Panel at the kick-off meeting. The crash costs are based on industry average costs presented in the FHWA interim bulletin on life-cycle cost analysis (Walls and Smith 1998) for various types of accidents using the crash data provided by the SDDOT. The vehicle operating costs are based on industry averages for the cost of operating vehicles on paved surfaces that are converted for different surface types using an approach developed by Winfrey (1969).

Task 5. With the assistance of the Technical Panel, identify a sample of local highway segments in counties and townships willing to collect data necessary to calibrate the approved analytical models.

During the Technical Panel meeting, several agencies were identified that might have data that would be beneficial to the study. The County Superintendents in these agencies were contacted about participating in the study, as were the other County Superintendents in the State. Each county agency was contacted through the mail. Initially, a total of twenty-six of the sixty-six County Superintendents responded to the request for information and 16 indicated their willingness to participate in the study. The forms used to solicit interest in the study and to identify sections for consideration in the study for each of the four road surfaces (HMA, blotter, gravel, and stabilized gravel) are provided in Appendix B.

Those counties that were interested in participating in the study were provided survey forms to complete that requested specific section information including initial cost, maintenance costs and frequency, and other pertinent information that was needed in developing the overall methodology of the surfacing choice procedure. Examples of the form for each surface type, along with the survey form instructions, are provided in Appendix C.

During the study, additional counties were contacted in order to provide additional HMA and blotter data at higher ADT levels. Of the counties contacted, seven provided additional roadway section data during conversations with the research team or the Technical Panel. A list of all counties that participated in the study is provided in table 4-1.

Task 6. Provide guidelines to SDDOT and the selected counties and townships for collection of necessary data.

Data collection forms were developed and distributed to the Technical Panel for review. The forms were finalized and distributed to the counties for collecting cost and treatment data. The form requested detailed information for each section, including initial costs, maintenance costs and frequency, and other information that was considered important in differentiating cost factors. A form was created for each road surface type. Examples of the forms used to solicit cost data for each surface type and a copy of the survey form instructions are provided in Appendix C. The information provided by the counties supplied the information necessary for customizing the agency cost models used as defaults in the surface type decision methodology. Initially, sixteen counties provided detailed information for use during the study. Section information for seven additional counties was added during the study.

Task 7. Compile and assess the quality of data collected by the selected counties and townships.

The data from the sixteen original counties, which totaled ninety-five sections, were compiled into a spreadsheet. While the responses covered a range of roadway sections, the data were fairly limited for stabilized gravel roads and for all surface types in the mountainous region of the state.

The initial statistical analysis of the data revealed that additional clarification of the agency costs and performance information was needed. The research team conducted phone interviews with each participating county to identify sources of discrepancies in how the data were reported and/or to improve the consistency in the types of data that were reported. The resulting changes to the life-cycle costs were recorded in a summary spreadsheet.

Table 4-1. Counties that participated in SD2002-10 study.

County	Contact
Bon Homme	Mike Einrem
Codington	Rick Small
Custer	John Culberson
Davison	Duane Zard
Day	Charles Fromelt
Douglas	Travis Sparks
Edmunds	Lenny Uhrich
Gregory	Dick Deffenbaugh
Hand	Ron Blachford
Harding	Bill Jensen
Kingsbury	Dave Sorenson
Lawrence	Charles Williams
Lincoln	Tom Winter
McCook	Mike Kreutzfeldt
McPherson	Roger Rohwedder
Miner	Ron Krempges
Minnehaha	Bobby Meister
Pennington	Hiene Junge
Perkins	Jason Saunders
Potter	Ronald Tanner
Sanborn	Lee Goergen
Turner	Ron Schulte
Walworth	Gary Byre

After an initial statistical analysis of the data collected, the research team determined that additional data were needed for HMA and blotter roadway sections with ADT greater than 500 vehicles per day. The research team worked with several of the Technical Panel members to identify counties that could provide data for higher-volume roads and conducted phone interviews with the counties to obtain the necessary information. The Technical Panel members also aided in the data collection efforts by soliciting roadway section data from a few counties. A total of seven additional counties provided data for twenty-five additional roadway sections, and these sections were added to the summary spreadsheet. As a result of these efforts, the customized models used in the analysis are considered to be representative of conditions in South Dakota because they are based on cost information provided on 120 road sections in 23 counties within the State.

Task 8. Analyze the collected data to calibrate the economic models to conditions typically encountered in South Dakota.

A statistical analysis was conducted on the initial data received from the sixteen counties participating in the study. No statistical significance was found between roadway type and any of the variables investigated as part of the study, even after calling the agencies to improve the consistency in the types of data that were provided. To improve the results of the statistical analysis, the research team recommended that additional data for HMA and blotter roadway sections with ADT greater than 500 vehicles per day be obtained and the statistical analysis be repeated once the data were available.

Once all the additional data were obtained, the research team confirmed that ADT was statistically significant in calculating agency costs associated with HMA, blotter, and gravel surfaces so agency cost models based upon ADT could be developed for these surface types. Due to the limited amount of data available, the agency costs associated with stabilized gravel surfaces were not found to be statistically significant to ADT. Therefore, the research team proposed the consideration of stabilized gravel as a road surface option on roadway sections that are recommended for a gravel surface (based on life-cycle cost factors) as long as other criteria (such as high population densities or dust control needs) are also satisfied.

The research team also finalized the calibrated economic models for user costs. Vehicle operating costs were determined to be statistically significant in relation to ADT while crash costs were not. Therefore, vehicle operating costs were modeled as a function of ADT and crash costs were categorized based upon the frequency of fatality, injury, and personal damage crashes that occur within a given timeframe on a roadway section.

Task 9. Recommend a practical methodology for applying the calibrated economic models for the purpose of deciding whether and when to maintain, upgrade, or downgrade surfacing types.

A methodology for applying the models to road surfacing decisions was created. The methodology was developed in such a way that it could be applied manually, using the default models developed during this study or actual cost data provided by the agency, or using an automated tool that applies either the default cost models or customized models based on inputs provided by the user. The default models were used to develop a graphical relationship between agency costs and ADT. They were also used to develop a relationship between vehicle operating costs and ADT. Lastly, a summary of crash costs based upon the potential for crashes was developed to estimate the cost of crash occurrences. Appropriate cost models are incorporated into both the manual and automated applications of the methodology.

The application of the methodology involves estimating the agency and user costs associated with a particular pavement section and summarizing them in a cost table. Often the very large costs associated with vehicle operating and crash costs overwhelm the agency costs (construction and maintenance) of a specific project. Therefore, the methodology allows the user to exclude user costs or reduce the user costs by scaling them to be more in line with the agency costs. Once agency and user costs are estimated, other issues such as politics, growth rates, housing concentration/dust control needs, mail routes, and industry/truck traffic can be taken into consideration for the selection of the most appropriate roadway surface.

Task 10. Prepare a 4 to 8 page "Technical Brief," suitable for distribution to local agencies through the South Dakota local transportation assistance program (SDLTAP), describing the methodology and demonstrating its manual application.

The manual application of the methodology developed in Task 9 is explained in a stand-alone *Technical Brief*. The *Technical Brief* was developed for distribution through both the SDLTAP and the LGA. It presents a summary of the methodology that was developed and explains the application of the methodology for making pavement surface type decisions. An example in the *Technical Brief* illustrates the use of the manual tool to determine the most cost-effective surface for a representative situation.

Task 11. Prepare, in spreadsheet or other suitable form, software that the SDLTAP can use to analyze cases at specific locations in South Dakota.

In addition to the manual application, the research team developed an automated tool that uses a spreadsheet to calculate agency and user life-cycle costs based on inputs provided by the agency. Alternatively, the spreadsheet tool can be used to apply the default models in the absence of more specific cost models within an agency. The tool makes use of simple user interfaces to step the user through the selection of the most cost-effective road surface type for a given set of circumstances.

The final tool allows consideration of any combination of agency costs, user costs, and/or non-economic costs for each surface type being considered and allows the default treatment costs and frequencies or actual data in the cost calculations. To aid the user, a brief *User's Guide* was developed for distribution with the software tool.

Task 12. Prepare a Final Report and Executive Summary of the research methodology, findings, conclusions, and recommendations.

This document serves as the final report. The *Executive Summary* is included as chapter 1 of this document.

Task 13. Make executive presentations to the SDDOT Research Review Board and the South Dakota Association of Counties at the conclusion of the project.

The research team prepared a presentation for the annual meeting of the Association of Counties in early October 2003. A presentation to the SDDOT Research Review Board is scheduled for June 10, 2004. At that time, the Principal Investigator will present the findings of the research along with the Train-the-Trainer materials. The delivery of the Train-the-Trainer materials without the corresponding presentation of the materials to the South Dakota Association of Counties reflects a change from the original project scope. Due to the difficulty in scheduling meetings with the South Dakota Association of Counties in conjunction with the presentation to the SDDOT Research Review Board, the Technical Panel modified the scope to include the Train-the-Trainer materials as a deliverable.

5.0 FINDINGS AND CONCLUSIONS

Significant findings and conclusions from the study are presented in this section of the report. Findings from each of the major areas of the study are documented separately, as shown in table 5-1. The implementation recommendations that were developed as a result of these findings are presented in chapter 6.

Table 5-1. Organization of chapter 5.

Report Section	Topic Discussed
5.1	Literature Review
5.2	Data Assessment
5.3	Model Development
5.4	Application of the Methodology
5.5	Summary

5.1 Literature Review

A review of the literature confirms that while there is substantial documentation on decision-making for paved roads, there is a lack of guidance on maintaining, rehabilitating, and determining appropriate surface types for low-volume roads. In the past, having access to appropriate decision making tools for agencies managing low-volume roads has not been a high priority in the United States. However, these tools are very important to local agency managers because of the number of miles of local roads that have been built and the expectation by users that the network will be maintained in relatively good condition. Today it is difficult for local agencies to meet this expectation because financial pressures are limiting the ability of local agencies (including municipal agencies, counties, and states) to maintain road conditions. Complicating the issue is the tendency for agencies to allocate funds to higher volume roads first, resulting in further deterioration of the local road network. The availability of tools to assist local agency managers to address these types of issues has become a much greater priority than it was in the past.

The SDDOT has been addressing various aspects of decision-making for local roads since the 1980s. The *Local Roads Needs Study* that was performed over a decade ago (ERES 1991) references a 1984 SDDOT study that was conducted to determine low volume road funding needs. Incidentally, the 1991 report states that the findings of the 1984 study were not well accepted and were never used to address the identified funding needs.

The objectives of the 1991 study of local roads were to identify appropriate factors to be considered in identifying levels of service (LOS) for county roads and bridges, to establish design and maintenance standards appropriate for various defined LOS, and to estimate county funding requirements based upon the developed standards. The report recommends design and maintenance standards for roads and bridges on a subset of South Dakota's transportation infrastructure, but does not really address how to make decisions about the most appropriate surface type.

The same is true, perhaps to a lesser extent, for the series of three guides that was produced as part of a 1995 study for the SDDOT (Beckemeyer 1995; Beckemeyer and McPeak 1995; Broten and Beckemeyer 1995). That study produced guidance on how to evaluate local roads, how to design, maintain, and rehabilitate these roads, and how to establish systems to manage low volume roads. From the standpoint of the current research project, the guides offer useful information on how to design, maintain, and manage local roads, but do not assist in making decisions when faced with financial constraints for road maintenance. In other words, in an ideal world where no constraints existed, the results of the 1995 study could be used to help a local agency manage its road system. However, the results will not help that manager decide which roads need improvements and which roads should be allowed to deteriorate.

Of course, in the United States LVR are not completely ignored. The SDLTAP, in conjunction with the FHWA, recently developed a gravel road manual, *Gravel Roads: Maintenance and Design Manual* (Skorseth and Selim 2000). In addition to providing important design information, the manual contains an appendix which addresses the issue of when to pave a gravel road. The issue is addressed using a series of ten questions that provide a framework for making surfacing decisions. While the ideas presented in this appendix apply to the determination of when to pave a gravel road, the same concepts can be applied to the decisions regarding other surface types. Specifically, the same approach used to calculate vehicle operating costs in the Skorseth and Selim manual was utilized in the current research study. The approach is based on procedures that Winfrey developed for adjusting the vehicle operating costs based upon the roadway surface type, the speed of the roadway section, and the type of vehicle utilizing the roadway (Winfrey 1969).

An interesting report by Luhr and McCullough (1983) describes some analyses of low-volume road surface types using a pavement management system created for the U.S. Forest Service's LVR network. Of particular interest to the current SDDOT project is that three pavement types were considered—aggregate, surface treatment, and HMA—and the total life-cycle costs for each pavement type were evaluated based on different traffic mixes and traffic volumes. The results show that aggregate- and chip seal-surfaced pavements become more expensive than HMA-surfaced roads as traffic increases because their maintenance and rehabilitation costs become more expensive. The authors conclude that "economic evaluations are extremely important for low-volume road systems" and that significant savings may be realized when the appropriate pavement design and rehabilitation strategy for a given set of conditions is selected. While a limited data set is evaluated in their study, the authors' application of an economic analysis to the pavement surfacing selection process provided guidance during the SDDOT project.

A fairly recent study from North Dakota looks solely at strategies for maintaining that State's gravel roads (Smadi et al. 1999). The authors identify changes in the needs of rural road users, budget constraints, and a shortage of quality gravel as significant pressures that are affecting road surfacing decisions. The primary focus of the research is to evaluate when it is feasible to pave gravel roads. The authors note that the decision is not based solely on ADT, but that other factors should be considered. The report recommends the application of a life-cycle cost (LCC) analysis that considers conventional costs as well as user costs and opportunity costs. Specifically, the approach includes the following steps (Smadi et al. 1999):

1. Identify gravel roads that have reached a threshold where there are candidates to be paved.
2. Collect data on the roads that include surface characteristics, traffic data, and annual maintenance costs.
3. Develop typical flexible pavement designs to meet current and future ADT using appropriate design standards.
4. Estimate LCC for the existing gravel surface (annual maintenance costs and user costs) and the designed paved surface (initial construction costs, annual maintenance costs, user costs) over the analysis period.
5. Select the surface alternative with the lowest LCC.

The authors acknowledge that legal, political, and budgetary constraints must also play a role in the process and may actually control the final selection. The authors also suggest a procedure for evaluating whether to reduce maintenance on gravel roads, and another procedure to evaluate whether to close a road. The findings and processes from this study were used to aid in the development of the methodology for the current SDDOT research study.

A recent study being conducted for the Minnesota Department of Transportation is examining when it is economically advantageous to upgrade and pave aggregate roads (Rukashaza-Mukome et al. 2003). The overall objective of the study is to identify the methods and costs of maintaining and upgrading an aggregate road. The preliminary results of the study provide a variety of useful information which can be applied to the current SDDOT study. The researchers determined that maintenance costs (on a per mile basis) are higher on gravel roads than bituminous surfaced roads around ADT ranges of 100 vpd and the maintenance costs show a considerable increase at ADT values greater than 200 vpd. The researchers conclude that these ADT ranges (100 to 200 vpd) provide valuable information on when to upgrade a gravel road. The study also reveals that snow removal costs for surfaced roadways exceed the costs on non-surfaced roadways by 20 percent; signifying the need to include snow removal costs in comparisons of maintenance cost differences between various surface types.

This brief background summary is based on the most applicable results of the comprehensive literature search conducted by the research team that focused on the following issues related to LVR: surface type selection, design and evaluation, life-cycle cost analysis and decision making, and rehabilitation and management. However, although several of the studies presented information that was useful to the research team during the development of the surface type selection methodology, none of the studies could be directly applied to the conditions and costs found in South Dakota without some modification. Therefore, this study advanced the state of the practice in South Dakota by customizing products to meet the needs of practitioners in the state.

In addition to these bodies of work referenced previously, additional references were reviewed and are summarized in Appendix A.

5.2 Data Assessment

Using the background provided by the results of the literature search along with input from the Technical Panel, the research team initiated efforts to collect the data needed to develop a decision methodology tailored to the conditions in South Dakota. The initial round of data collection from the county agencies in South Dakota provided data for ninety-five roadway sections. The initial construction and maintenance information provided the needed information for the project team to determine the agency life-cycle cost of each section.

The results of the agency cost calculations were summarized in a spreadsheet for use in a statistical analysis. The first statistical test conducted on the data was to summarize the average cost and average frequency (along with the standard deviation of the cost and frequency) of the different maintenance treatments associated with each surface type. This initial test revealed large standard deviations for all of the treatment costs, indicating discrepancies in the information provided by the various counties.

In addition to the review of the summary statistics, the data were used to test the statistical significance of several roadway characteristics (terrain, ADT, truck traffic, and subgrade condition) at predicting the agency cost. The statistical analysis was conducted by performing a conventional linear regression to predict the agency costs using each roadway characteristic independently. The conduct of the linear regression provides coefficients and the statistical significance probability of each predictor variable. Low probability values (less than 0.05) signify that the coefficient is statistically significant at predicting the given index (to a 95 percent confidence level). A statistically significant coefficient can be used as a predictor of the cost component it is modeling.

During the data analysis, the research team also calculated user costs for each of the ninety-five roadway sections in the study. Using the crash data and ADT supplied by SDDOT, the crash costs and vehicle operating costs were determined based upon a 20-year analysis period and a 3.5 percent discount rate. The user cost data was then analyzed statistically to determine if any roadway characteristic could be used to predict the user costs.

The initial regression analysis revealed that no characteristics were consistently statistically significant in predicting the agency or user costs for the various roadway types. Due to the lack of statistically significant characteristics and the large standard deviations in the cost data from the various counties, the research team and the Technical Panel decided that further clarification of the maintenance costs and frequency information was needed. In response, the research team reviewed the information that had been submitted and conducted follow-up calls with each participating agency to improve the reported information with the objective of improving the consistency of the data that were reported

The examination of agency costs revealed that clarification was needed for nearly every one of the ninety-five roadway sections for which data were provided. The initial data review also showed the annual maintenance costs for Pennington County were very large in comparison to the costs provided by the other counties in the study. A follow up discussion with the Pennington County revealed that the submitted maintenance costs included maintenance work (such as snow removal) that had not been included in the data from the other counties. Unfortunately, the county provided no new cost values, which excluded the cost of winter maintenance. Therefore, the APTech team calculated an average annual maintenance cost to use in the life-cycle cost analysis for the Pennington County roadway sections. All other cost data were clarified through phone calls with the participating counties.

Using the revised cost information that resulted from the phone calls with county representatives, new agency life-cycle costs were determined for the roadway sections. Although ADT was not significant in predicting the agency costs during the initial analysis, it was this roadway characteristic that seemed most favorable for providing statistical significance in predicting agency costs. Therefore, further statistical analysis focused on the use of ADT to predict the agency costs for each roadway surface type. The analysis of the revised data indicates that ADT is statistically significant in predicting agency costs for HMA, blotter, and gravel roads. However, ADT was not statistically significant as a predictor for agency costs on stabilized gravel, nor were any of the other tested variables found to be statistically significant. For that reason, the research team concentrated on HMA, blotter, and gravel surfaces in developing the models and developed an alternate approach for selecting stabilized gravel as a surface type. This approach was reasonable due to the limited use of stabilized gravel in the participating agencies in South Dakota.

Before finalizing the cost models, the data set for each surface type was checked for outliers. Cook's distance statistical test, which measures the influence of individual observations on the regression coefficients, indicated that one data point for a blotter section and two data points for HMA sections were influencing (skewing) the overall slope of the linear regression curve and therefore were labeled as outliers. When removed from the data set, ADT was no longer significant in predicting the agency costs for HMA or blotter roads.

Further investigation into the outliers indicated that the outliers represented sections with higher ADT values, indicating a dependence of the cost models on those sections with high ADT values. Based upon this finding, the research team and the Technical Panel decided to collect additional data on HMA and blotter road sections with ADT values greater than 500 vpd to provide enough data so that the sections with higher ADTs no longer skewed the results of the overall regression analysis. To provide the additional information, seven counties were contacted by phone. Follow up phone calls were very successful at collecting the necessary information and, in retrospect, determined that phone interviews with county personnel may have been a better way of collecting the information needed during this study rather than the survey approach that was used. The research team noted that the response to the initial request for information via mail was relatively weak, while those agencies contacted via phone during the search for additional data were more receptive to participation in the study. The research team also noted that the additional cost data were found to directly address the project needs and were used without further modification.

Using the expanded database, the statistical analysis was then repeated. The results show that with the additional data, ADT again became significant at predicting the agency cost for HMA, blotter, and gravel. Cook's distance was checked again for all roadway sections in the analysis, and two more HMA sections (both with ADT values greater than 3,000) and one blotter section (with an ADT value of 770) were found to be skewing the linear regression curve. Once the three outliers were removed from the data set, the statistical significance of the ADT was reevaluated and determined to still provide significance at predicting agency costs for all surface types except stabilized gravel. The results of the statistical analysis are shown in Appendix D. Using the final data set, customized agency cost models were developed.

A similar study was conducted with user cost data provided by the SDDOT. The analysis used 10 years of crash occurrence data and the most recent ADT information to calculate the crash costs and the vehicle operating costs for each roadway section.

The research team summarized the crash occurrence data into an average yearly per mile crash occurrence rate for each roadway section included in the study. The data showed a wide variety of crash occurrence rates for each of the three crash categories (fatality, injury, and property damage only) for each surface type. Since a combination of many factors can influence crash occurrences, it is difficult to predict occurrences based on only one roadway factor (such as ADT). Issues such as roadway geometrics, pavement condition, environmental conditions, surrounding vegetation, and potential reckless driving can all contribute to crash occurrences and are difficult, if not impossible, to classify and model. For this reason, crash costs were not modeled based on a single variable and, as described later, an alternate approach was developed.

To develop crash costs for each section, crash occurrence rates were multiplied by the standard crash cost rates provided by the FHWA (1999) in order to determine the crash costs in 1990 dollars. These costs were then converted to 2003 dollars and present worth costs were determined based upon a 20-year life-cycle cost analysis using a 3.5 percent discount rate. The standard crash costs used for each of the three crash types (fatality, injury, and property damage only) are shown in table 5-2. For the identification of standard crash costs, all roadway sections are assumed to be rural highway segments.

Table 5-2. Standard crash costs (1990 dollars) (FHWA 1999).

Intersection or Facility Type	**Fatality**		**Nonfatal Injury**		**Property Damage Only (PDO)**	
	Rural	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**
RR Grade Crossing	$1,008,000	$994,000	$252,000	$133,000	$159,000	$309,000
Intersection/Interchange	$1,059,000	$932,000	$219,000	$143,000	$198,000	$135,000
Bridge	$1,111,000	$978,000	$249,000	$143,000	$214,000	$127,000
Highway Segment	$1,111,000	$978,000	$249,000	$143,000	$214,000	$127,000

The crash costs were tested against ADT values for each surface type and ADT was not found to be statistically significant in predicting the crash costs of the sections. Due to the lack of statistical significance, a decision was made to create the models using levels of crash occurrences.

To calculate vehicle operating costs, the ADT information provided by the DOT was used in conjunction with the terrain type and speed limit of the road sections. Based upon the analysis methodology presented by Winfrey (1969), vehicle operating costs were determined using the vehicle running costs presented in the reference as the foundation of the cost calculations. Tables summarizing vehicle operating costs (running costs) for different vehicles are included as tables E-1 through E-5 in Appendix E. The tables represent the costs associated with operating a vehicle on an HMA surfaced pavement and include the cost of fuel, tires, engine oil, maintenance, and depreciation for five different vehicle types: passenger car, commercial delivery vehicle, single unit truck having dual rear wheels, 2-S2 (2-axle tractor-semitrailer) truck, and 3-S2 (3-axle tractor-semitrailer) truck. Due to the absence of truck distribution data on rural roads in South Dakota, the following traffic breakdown is used as the default in calculating the vehicle operating costs for all roadway sections: passenger car (97 percent), commercial delivery vehicle (1 percent), single unit truck (1 percent), 2-S2 (2-axle tractor-semitrailer) truck (0.5 percent), and 3-S2 (3-axle tractor-semitrailer) truck (0.5 percent).

Vehicle operating costs for each of the traffic categories were calculated using the tables in Appendix E and the assumption that roadway sections with flat, rolling, and mountainous terrain had grade percentages of level, 2 percent, and 5 percent, respectively. The posted speed limit for each section was also used to determine the appropriate vehicle operating cost for each vehicle type on the roadway section. Once vehicle operating costs were determined from the tables, further conversions were made to the cost of operating on surfaces other than HMA. Based upon data presented by Winfrey, a plot for converting vehicle operating costs on a HMA section to vehicle operating costs on a gravel section was developed and is shown in figure 5-1. As shown in the figure, vehicle operating costs are higher on gravel roads than on paved surfaces.

Winfrey also provides guidance on how to handle the conversion of vehicle operating costs for other surfaces. Based upon the recommendations, the magnitude of the conversion factor for the gravel sections at the various speeds was adjusted by the research team for other pavement surfaces. Blotter surfaces were determined to have one third of the magnitude of the gravel conversion factor while stabilized gravel surfaces were estimated to have two-thirds of the magnitude of the conversion factor for gravel. These factors were then applied to calculate the final vehicle operating costs for each roadway section. The costs were calculated in 1969 dollars and converted to 2003 dollars for the study. After the conversion, the present worth value of the vehicle operating costs were based upon a 20-year life-cycle cost analysis using a 3.5 percent discount rate.

ADT was then tested and determined to be statistical significant in predicting the vehicle operating costs. Final models that predicted vehicle operating cost based upon ADT were then developed. Only those sections used in developing the agency cost calculations were included in the development of cost models for crash costs and vehicle operating costs.

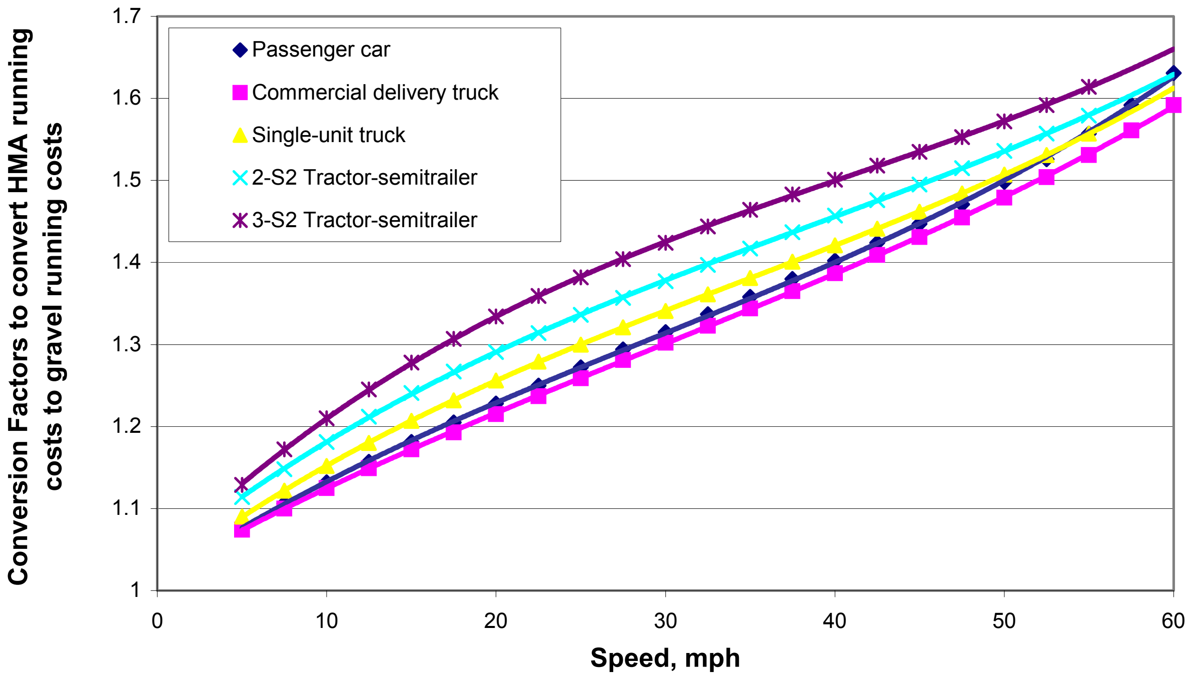


Figure 5-1. Factors for converting vehicle operating costs for a HMA section to vehicle operating costs for a gravel section.

The resulting agency costs, user costs, and ADT information were compiled for all roadway sections included in the study and are provided in Appendix F (tables F-1 through F-4). In addition to this information, additional section information including terrain type, subgrade type, truck traffic level, distance to aggregate source, speed limit, and housing density is also provided in Appendix F for HMA, blotter, gravel, and stabilized gravel in tables F-5 through F-8. Crash data for each section is also provided in Appendix F. Tables F-9 through F-12 provide crash occurrence rates on a per mile basis for the ten years of data supplied by SDDOT. The tables in Appendix F provide the section-by-section information used in developing the final default models explained below.

5.3 Model Development

Once the statistical tests were complete, the final default cost models for the surface type selection procedure were created using 2003 dollars. The procedure was created using 2003 dollars because 2004 conversion factors (consumer price indices) were not available during this phase of the study. The resulting agency cost models are shown in figure 5-2.

A review of this model shows that when only average agency costs are considered, gravel, blotter, and HMA seem to be the most cost effective surface between ADT ranges of 0 to 150 vpd, 150 to 660 vpd, and 660 vpd and greater, respectively. The findings are in line with values expected by the research team and correspond with other current studies on this subject matter. As mentioned in the literature review section of this report, researchers working on a study for MnDOT determined that an ADT range of 100 to 200 vpd provided an acceptable traffic level for upgrading a gravel road (Rukashaza-Mukome et. al 2003).

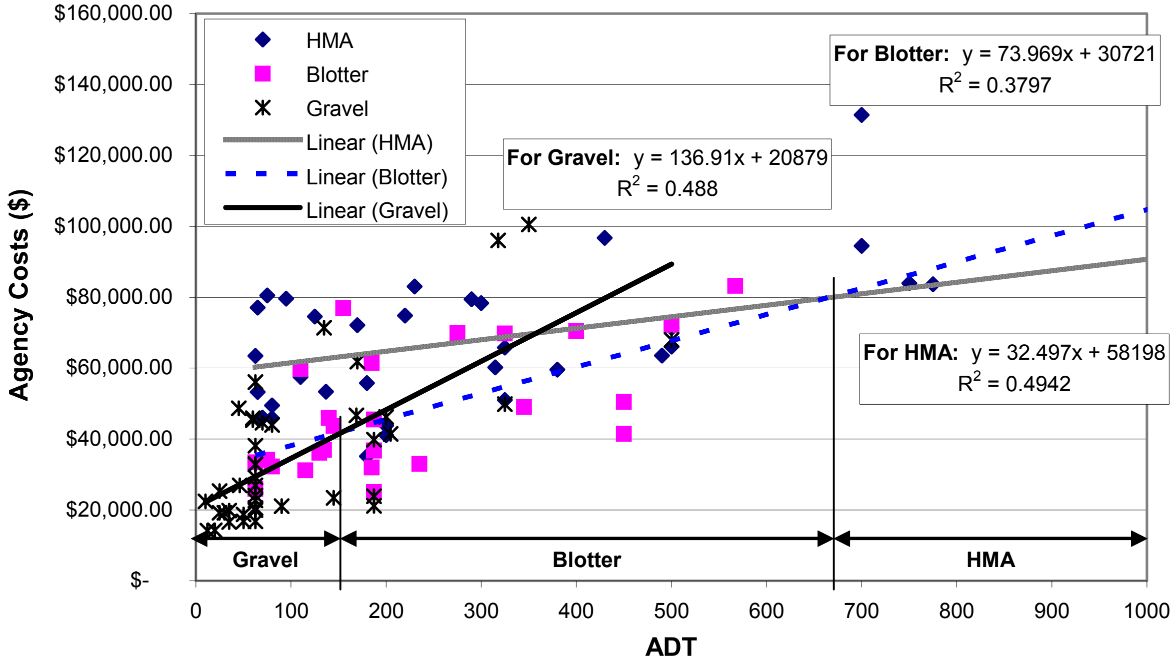


Figure 5-2. Default 20-year agency cost models (per mile).

An assessment of the default models resulted in several observations that might enhance the results of this study if investigated further. For instance, the linear regression models reflected in figure 5-2 have reasonable coefficients of determination (R^2), but these could be improved by collecting more data to better account for the data variability. Also, if agency cost models are ever updated, the SDDOT should consider including snow removal as a maintenance cost. Other studies have shown these costs to be significantly different for the various surface types so the collection of this data and review of its use is warranted if making updates to the models (Rukashaza-Mukome et. al 2003).

In addition to the development of default models for estimating agency costs, models were developed to depict the relationship between vehicle operating costs and ADT. These costs represent the differences in the wear and tear on a vehicle associated with driving on various roadway surfaces. Figure 5-3 displays the vehicle operating cost per mile of roadway for roads with ADT values of 0 to 1000 vehicles per day. The default models have R^2 values of 0.94 or higher, which indicate a strong correlation between vehicle operating cost and ADT. As expected, the vehicle operating costs are lowest on HMA-surfaced roadway and continue to increase for blotter, stabilized gravel and gravel surfaces, respectively.

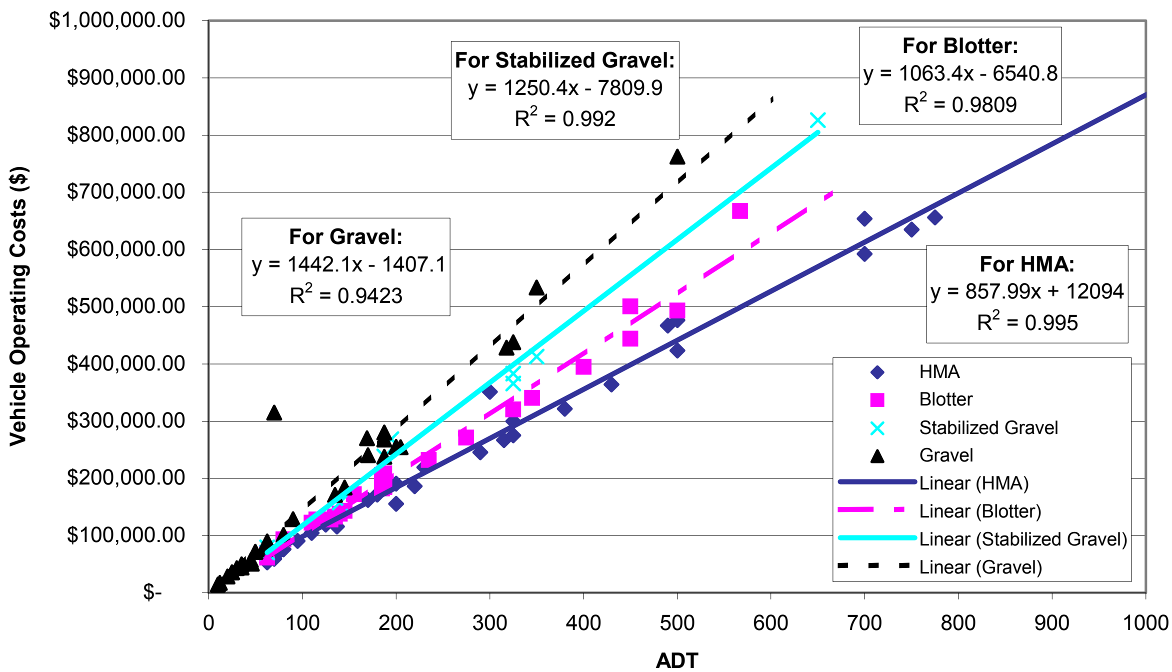


Figure 5-3. Default 20-year vehicle operating cost models (per mile).

Since ADT did not prove to be statistically significant in predicting crash costs, other methods for creating these models were examined. As discussed earlier, crash costs were summarized for each section in the study based on the type of crashes that occurred (fatality, injury, and/or property damage only). For each section, 20-year crash costs were determined by annualizing the cost of crashes for a 10-year period and applying that cost over the analysis period. Using this information, plots showing crash costs for the various sections were developed and four crash cost categories were assigned using engineering judgment. The four categories were developed so that crash costs could be assigned to a section using the potential for each of the three crash types, including none (no potential for crashes), low, medium, or high. The resulting plots are shown in figures 5-4 through 5-7, respectively. Descriptions of each of the four crash potential categories are provided in table 5-3. These categories represent the total number of crashes expected over a 10-year period on a 1-mile section of roadway. While crash potential is estimated over a 10-year period, the crash costs were determined for a 20-year analysis. The crash potential rates were provided for a 10-year period rather than a 20-year period because it is easier to estimate crash potential over a shorter time period such as 10 years versus a longer time period of 20 years.

Crash costs for the sections that fell in each crash category were averaged to develop the final rural default crash cost models that are shown in figure 5-8. These 20-year default crash costs were then utilized in the *Technical Brief* while the automated software tool utilizes the annualized crash cost and applies it over the analysis period specified in the tool (the default analysis period is 20 years). The software tool also includes default crash costs for urban sections.

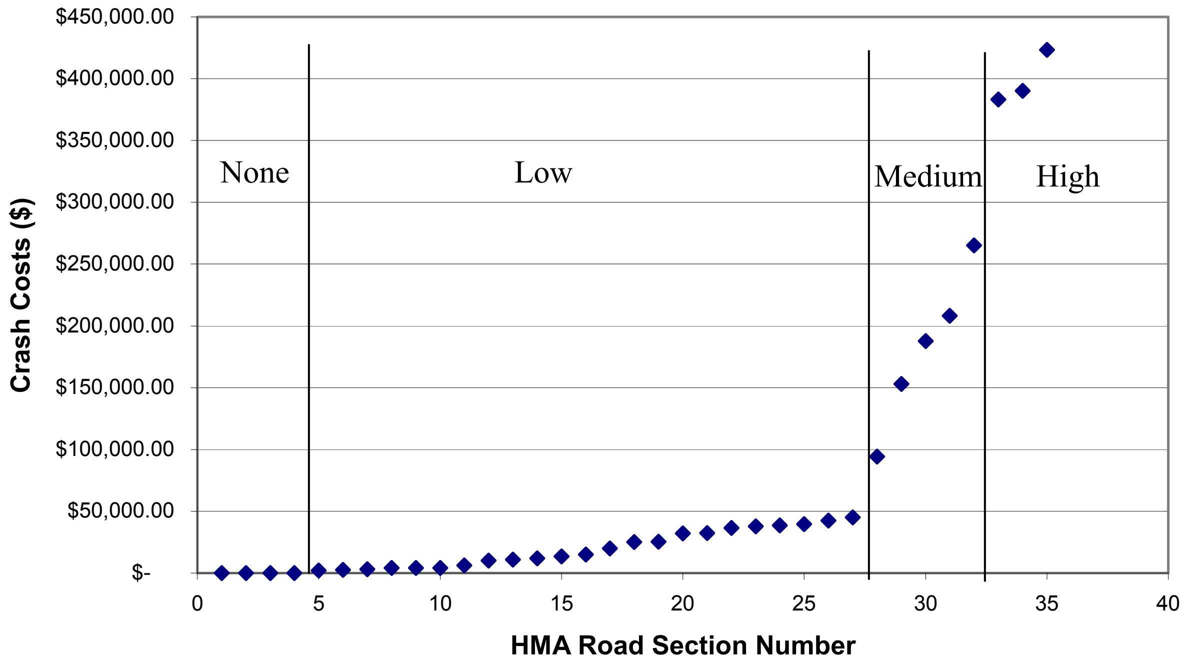


Figure 5-4. Average 20-year crash costs by crash potential on HMA sections (per mile).

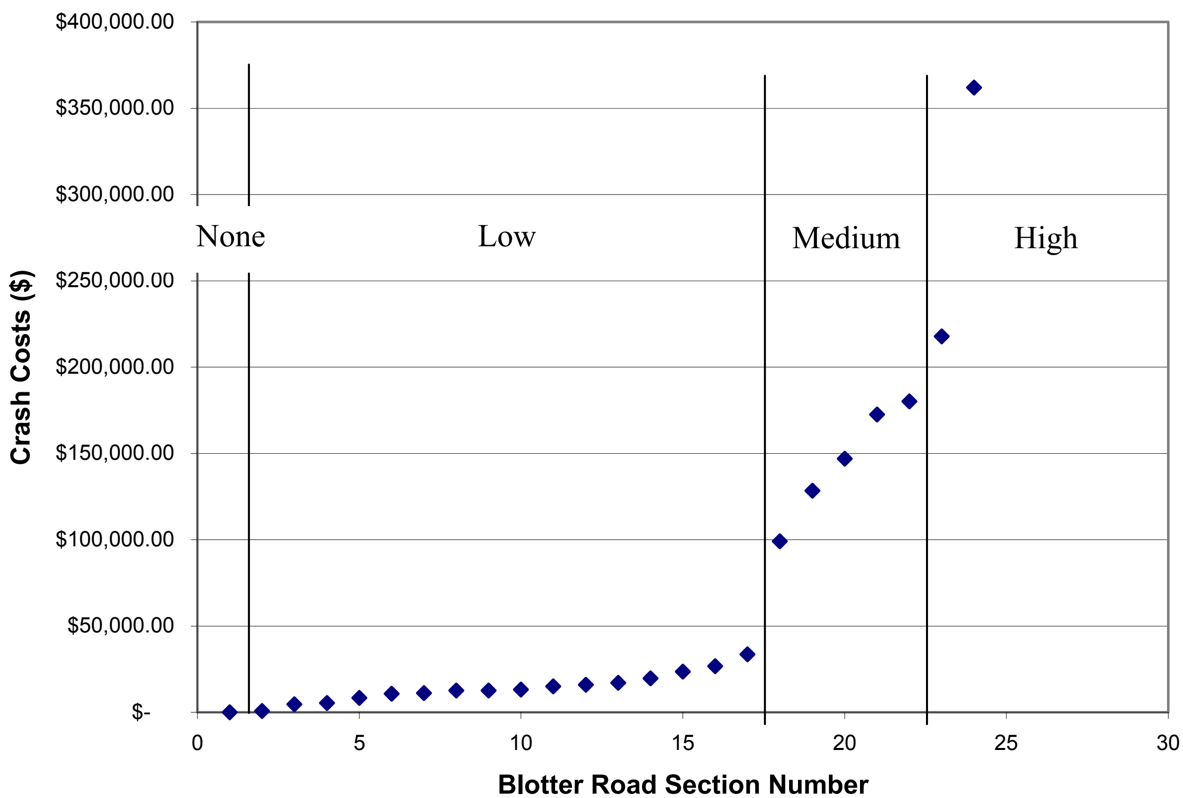


Figure 5-5. Average 20-year crash costs by crash potential on blotter sections (per mile).

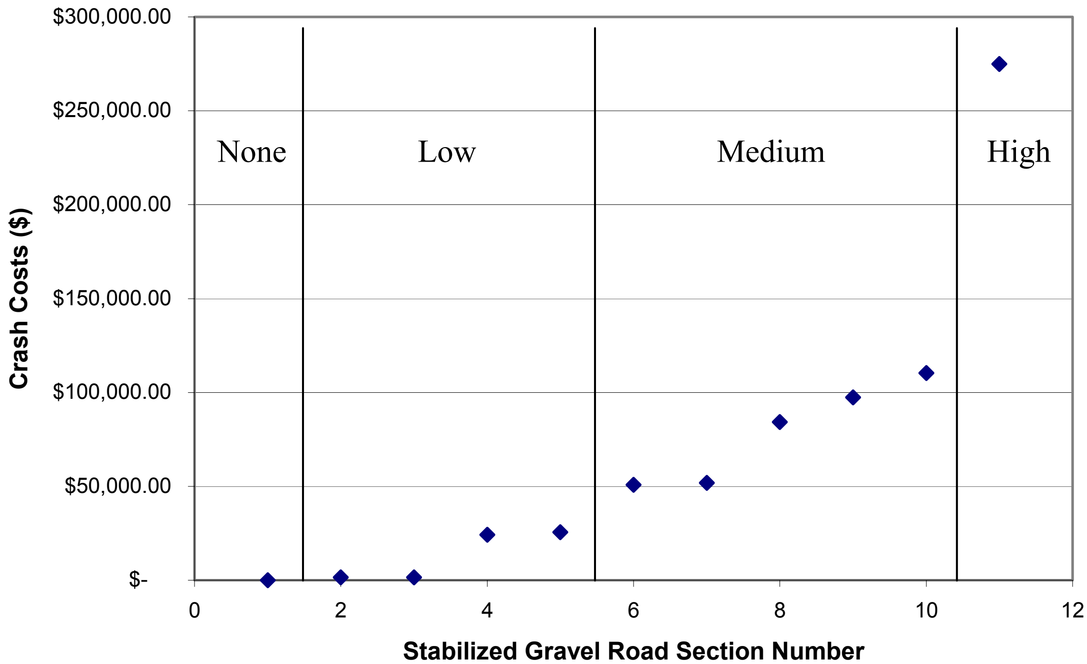


Figure 5-6. Average 20-year crash costs by crash potential on stabilized gravel sections (per mile).

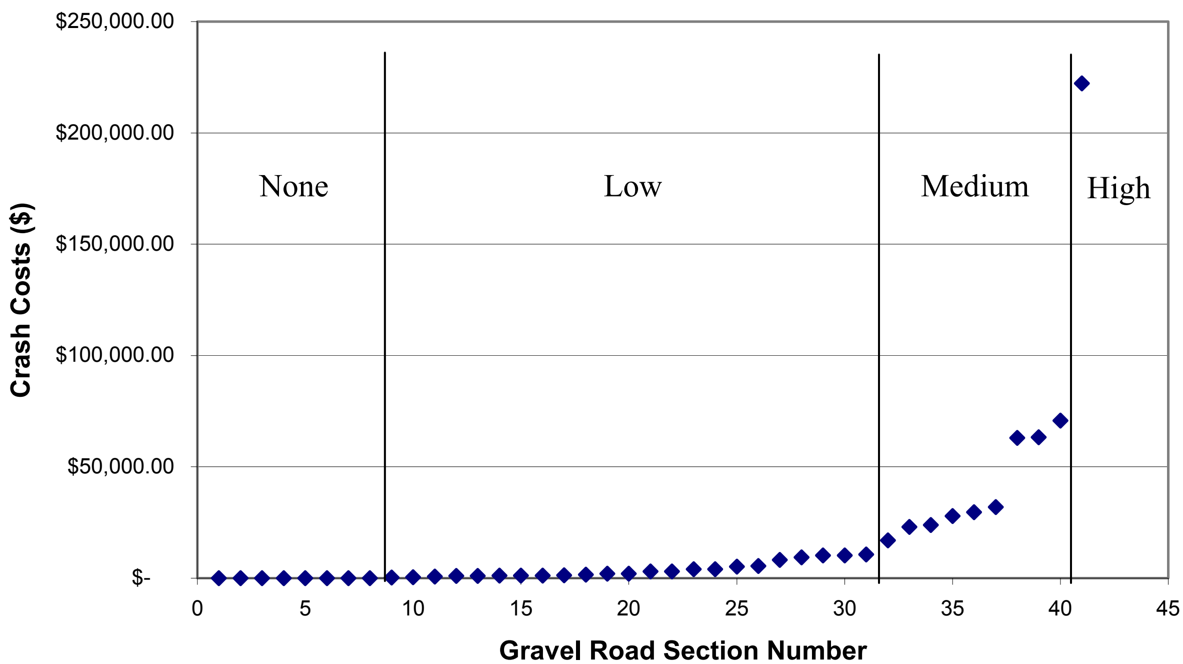
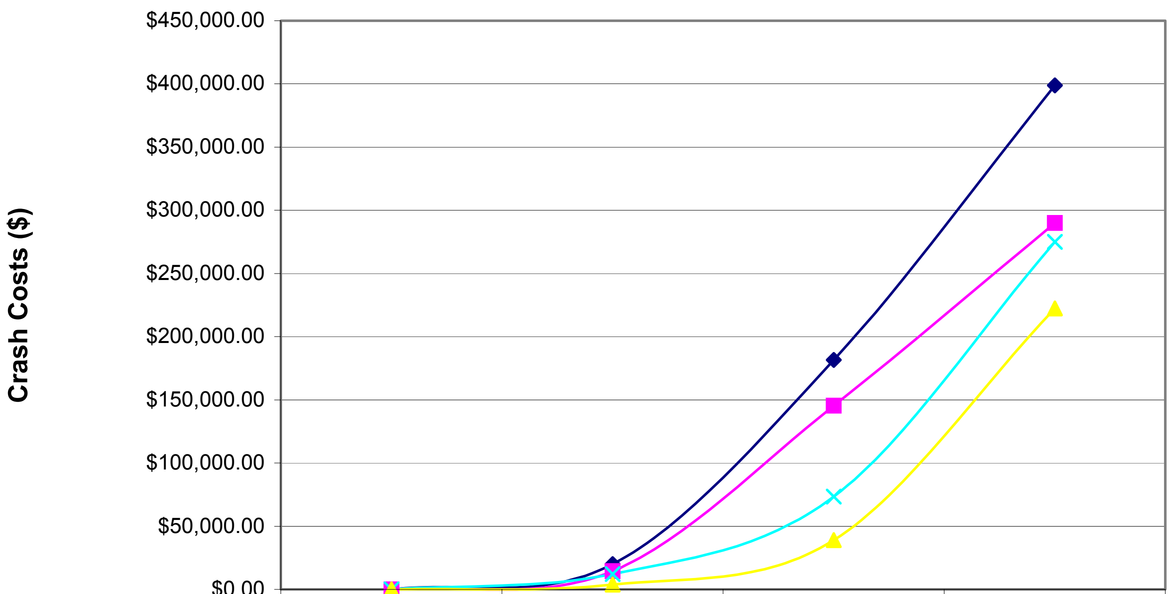


Figure 5-7. Average 20-year crash costs by crash potential on gravel sections (per mile).

Table 5-3. Crash Potential.*

Crash Potential	Expected number of crashes by type over a 10 year period
None	No fatalities, injuries, or personal damage only crashes
Low	No fatalities, one or fewer injury crashes, and fewer than four personal damage only crashes
Medium	*Option 1:* No fatalities, one to three injury crashes, and four to six personal damage only crashes
	Option 2: One fatality, one to two injury crashes, and four or fewer personal damage only crashes
High	*Option 1:* No fatalities, more than three injury crashes, and more than six personal damage only crashes
	Option 2: One fatality, more than two injury crashes, and more than four personal damage only crashes
	Option 3: More than one fatality

*Crash rates based upon 1-mile roadway section.



	None	Low	Medium	High
HMA	$-	$20,110	$181,670	$398,900
Blotter	$-	$14,470	$145,420	$289,860
Stabilized Gravel	$-	$12,250	$73,430	$275,000
Gravel	$-	$3,800	$38,920	$222,300

Figure 5-8. Average 20-year crash costs per surface type per crash potential level (per mile).

5.4 Application of the Methodology

After developing default cost models tailored to conditions in South Dakota, tools were developed so the methodology could be applied by local agencies within the State. Two approaches were developed for using the methodology: a manual method and an automated method. The manual procedure is documented in a *Technical Brief*. The automated application of the methodology makes use of a spreadsheet tool that allows the user to apply the default models developed during the study or to input cost data specific to a particular road section. Each of these applications is described further in the following sections.

5.4.1 Technical Brief

The *Technical Brief* provides a simple step-by-step procedure for applying the methodology developed for the project. While the software tool provides the potential for a more robust analysis, the *Brief* provides those users who are not comfortable using the computerized software tool with a manual procedure for applying the methodology for determining an appropriate surface type for a specific roadway section.

A copy of the *Technical Brief* that was developed for this project is included in Appendix G. In order to keep the *Brief* concise and straightforward, some of the details of its development are excluded from the document. An effort was made to use general terms and exclude technical terms and details that might confuse the non-technical user.

One aspect of the simplification was not using the term "life-cycle cost" when referring to the agency or user costs throughout the *Technical Brief*, because there was a concern that many users would not be accustomed to this term and its use would either cause confusion or require a detailed discussion of life-cycle costing and the issues associated with it. Furthermore, an explanation was not provided to clarify that costs displayed in the figures and tables reflect present worth costs from a 20-year life-cycle cost analysis that used a 3.5 percent discount rate.

The ease of use of the *Brief* is due in part to the use of models that were developed using average costs. As discussed earlier in this report, all models were developed using least squared linear regression or averaging techniques to summarize costs. Therefore, surfacing decisions made for a specific roadway section using the *Technical Brief* are largely based upon average costs of the roadway sections collected during the study (although specific agency costs can be entered). While the study tried to incorporate data from the entire State of South Dakota, data were obtained for twenty-three of sixty-six counties in the state. The data were then "averaged" to create the models. The models have inherent variability due to the varied nature of the section characteristics and the cost information provided by the limited counties included in the study.

As detailed in Appendix G, the methodology for determining the appropriate surface type involves first selecting a given road section for analysis. After defining the road section name, location, section length, and ADT information, the agency costs for each pavement surface can be calculated using a life-cycle cost approach. It should be noted that the life-cycle cost value calculated does not consider the time value of money or salvage value when determining the final agency costs.

The process requires the user to enter information regarding treatment timing and associated costs into a form that guides the user through the agency cost calculation. For those agencies lacking internal information regarding treatment timings and costs on the various surface types, default values are provided. Initial default values were determined by averaging the data supplied by the counties that participated in the study. The initial cost inputs are summarized in tables 5-4 through 5-7. To utilize these costs in the analysis, data were averaged using 100-point ADT ranges starting at a zero ADT value. The resulting data revealed fluctuations in the treatment costs and application cycles that did not match expected patterns. These fluctuations are due to the differences in costs and timings that were reported by the participating agencies.

To eliminate the impact of these counterintuitive trends, such as decreasing cost or treatment timing of a specific treatment type with increasing ADT, a decision was made by the Technical Panel to supplement the default values with expert opinion in order to provide logical cost and treatment timing progressions. New default costs and timings were created for use in the Technical Brief and the software tool. These final default values are provided in tables 5-8 through 5-11. It should be noted that the default initial/major rehabilitation costs included in the tables do not reflect the costs of upgrading the road from one surface type to another. Therefore, if the user of the tool wants to incorporate upgrade costs into the analysis, the default values for initial construction/major rehabilitation need to be increased by the appropriate amount.

Table 5-4. Construction and maintenance costs determined from South Dakota agency input for HMA roadways based upon ADT levels.

ADT	Initial Const. or Major Rehab. Cost ($/mile)	Crack Seal		Seal Coat		Overlay		Striping and Marking		Patching/ Annual Maint. Cost ($/mile)
		Years between app.	Cost ($/ mile)	Years between app.	Cost ($/ mile)	Years between app.	Cost ($/ mile)	Years between app.	Cost ($/ mile)	
0-99	43,000	5	1,500	5	7,000	21	43,000	3	210	500
100-199	45,000	3	1,100	5	6,500	17	45,000	4	250	614
200-299	35,000	3	1,200	4	7,000	20	35,000	5	330	1,070
300-399	37,000	7	1,700	6	7,000	20	37,000	5	360	1,630
400-499	40,000	3	900	4	5,400	15	40,000	4	310	300
500-599	39,000	6	700	4	7,300	20	39,000	4	280	400
600-699	39,000	6	700	4	7,300	20	39,000	4	280	400
> 700	43,000	5	1,600	6	9,000	22	62,000	4	460	100

Note: All costs are per mile.

Table 5-5. Construction and maintenance costs determined from South Dakota agency input for blotter roadways based upon ADT levels.

ADT	Initial Construction or Major Rehab. Cost ($/mile)	Seal Coat		Striping and Marking		Patching/Annual Maint. Cost ($/mile)
		Years between app.	Cost ($/mile)	Years between app.	Cost ($/mile)	
0-99	9,530	5	9,100	5	430	530
100-199	6,950	5	6,700	5	250	920
200-299	9,180	4	8,900	5	280	1,250
300-399	7,850	4	7,400	4	450	1,260
400-499	7,170	5	6,800	5	370	1,430
> 500	9,540	5	9,100	3	440	3,150

Note: All costs are per mile.

Table 5-6. Construction and maintenance costs determined from South Dakota agency input for gravel roadways based upon ADT levels.

ADT	Initial Construction or Major Rehab. Cost ($/mile)	Blading		Regravel		Spot Gravel/ Annual Maint. Cost ($/mile)
		Times per year	Cost ($/mile)	Years between app.	Cost ($/mile)	
0-99	4,500	17	45	8	4,500	350
100-199	3,700	20	40	6	3,700	800
200-299	3,700	30	35	6	3,700	1,070
> 300	7,036	4	65	3	7,036	2,420

Note: All costs are per mile.

Table 5-7. Construction and maintenance costs determined from South Dakota agency input for stabilized gravel roadways based upon ADT levels.

ADT	Initial Construction/ Major Rehab. Cost ($/mile)	Dust Control		Blading		Regravel		Reshape Cross Section		Spot Gravel/ Annual Maint. Cost ($/mile)
		Years between app.	Cost ($/ mile)	Times per year	Cost ($/ mile)	Years between app.	Cost ($/mile)	Years between app.	Cost ($/ mile)	
0-99	5,000	1	2,700	24	40	12	2,300	--	--	500
100-199	8,154	1	3,300	20	40	5	4,854	--	--	333
200-299	8,154	1	3,300	20	40	5	4,854	--	--	333
> 300	19,716	1	2,300	4	380	10	17,416	10	3,400	3,635

Note: All costs are per mile.

Table 5-8. Final default construction and maintenance costs for HMA roadways in South Dakota based upon ADT levels.

ADT	Initial Const. or Major Rehab. Cost ($/mile)	Crack Seal		Seal Coat		Overlay		Striping and Marking		Patching/ Annual Maint. Cost ($/mile)
		Years between app.	Cost ($/ mile)	Years between app.	Cost ($/ mile)	Years between app.	Cost ($/ mile)	Years between app.	Cost ($/ mile)	
0-99	35,000	3	900	5	6,500	21	35,000	5	210	500
100-199	35,000	3	900	5	6,500	17	35,000	4	250	500
200-299	37,000	3	1,200	4	7,000	20	37,000	4	280	500
300-399	37,000	3	1,200	4	7,000	20	37,000	4	280	500
400-499	39,000	5	1,600	4	7,300	20	39,000	4	310	500
500-599	40,000	6	1,600	4	7,300	20	40,000	4	320	500
600-699	43,000	6	1,600	4	7,300	20	50,000	4	360	500
> 700	43,000	6	1,600	4	7,300	20	50,000	4	360	500

Note: All costs are per mile.

Table 5-9. Final default construction and maintenance costs for blotter roadways in South Dakota based upon ADT levels.

ADT	Initial Construction or Major Rehab. Cost ($/mile)	Seal Coat		Striping and Marking		Patching/Annual Maint. Cost ($/mile)
		Years between app.	Cost ($/mile)	Years between app.	Cost ($/mile)	
0-99	7,000	5	7,000	5	250	530
100-199	7,000	5	7,000	5	250	920
200-299	7,170	4	7,170	4	280	1,250
300-399	7,850	4	7,850	4	370	1,260
400-499	9,180	5	9,180	5	440	1,430
> 500	9,540	4	9,540	3	450	3,150

Note: All costs are per mile.

Table 5-10. Final default construction and maintenance costs for gravel roadways in South Dakota based upon ADT levels.

ADT	Initial Construction or Major Rehab. Cost ($/mile)	Blading		Regravel		Spot Gravel/ Annual Maint. Cost ($/mile)
		Times per year	Cost ($/mile)	Years between app.	Cost ($/mile)	
0-99	3,700	17	45	8	3,700	350
100-199	3,700	20	45	8	3,700	800
200-299	4,500	30	50	6	4,500	1,070
> 300	7,036	50	65	6	7,036	2,420

Note: All costs are per mile.

Table 5-11. Final default construction and maintenance costs for stabilized gravel roadways in South Dakota based upon ADT levels.

ADT	Initial Construction/ Major Rehab. Cost ($/mile)	Dust Control		Blading		Regravel		Reshape Cross Section		Spot Gravel/ Annual Maint. Cost ($/mile)
		Years between app.	Cost ($/ mile)	Times per year	Cost ($/ mile)	Years between app.	Cost ($/mile)	Years between app.	Cost ($/ mile)	
0-99	5,000	1	2,700	4	40	12	2,300	--	--	500
100-199	8,154	1	3,300	4	40	5	4,854	--	--	333
200-299	8,154	1	3,300	4	40	5	4,854	--	--	333
> 300	19,716	1	2,300	6	380	10	17,416	10	3,400	3,635

Note: All costs are per mile.

A plot of vehicle operating costs versus ADT then allows the user of the *Technical Brief* to determine the vehicle operating cost portion of the user costs. The second portion of the user costs, the crash costs, is determined based upon an estimated crash potential level for the given roadway section. Guidelines are provided to help the user determine the appropriate crash potential level.

In determining the economic impact of each surface type, a user can incorporate agency costs and/or user costs depending upon the weight that the agency wants to give to each cost. In fact, the procedure allows the user to weight the user costs because the user costs often overwhelm the agency costs. Therefore, the user may decide to exclude user costs or reduce the associated costs in order to provide costs that are more in line with expected values. Example ranges of weighting factors are provided as guidance for the user in the *Technical Brief*.

The methodology developed during the project not only allows users to incorporate economic factors, but also allows non-economic factors to be considered if desired. The non-economic factors are more subjective and difficult to quantify, but allow issues such as politics, growth rates, housing concentrations, mail routes, and industry/truck traffic to be weighted into the final surfacing decision. The procedure requires the user to weight each of the factor categories, which includes a cost factor along with each non-economic factor, so that the weighting factors assigned to the desired factors total 100 percent. After weight factors are assigned, the user must assign scoring factors to each factor category for each surface type and then scores are determined for each surface by multiplying out weighting and scoring factors. The total scores for each surface type can then be determined by adding the total score for each factor category together. Finally, the surface type with the highest score is recommended as the appropriate surface type.

5.4.2 Automated Software Tool

The automated application of the methodology provides additional capabilities over the manual procedure outlined in the *Technical Brief*. The overall approach remains the same in the software tool as in the *Technical Brief* because the user can analyze agency costs, user costs, and non-economic factors to determine the appropriate surface type for a given roadway. The software tool allows the user to analyze section-specific cost and treatment details for the section being considered or default values can be used. The automated software tool has the ability to determine the agency and user life-cycle cost for any combination of section-specific details.

The foundation of the automated software is an Excel spreadsheet that uses the initial construction/last major rehabilitation cost, along with maintenance costs and frequency of treatments, to determine the 20-year present worth life-cycle agency and user costs. This spreadsheet allows the user to change parameters related to the roadway section and instantly see the changes to the life-cycle cost analysis and the recommendation of the most cost-effective surface type for the roadway section.

If a user does not have the data necessary to input all initial construction/last major rehabilitation cost and maintenance costs and frequencies for the various surface types they wish to analyze, default costs and timings can be used.

As in the manual procedure, the software tool allows the user to compare any combination of the four surface types: HMA, blotter, gravel, and stabilized gravel. The software also allows the user to alter "advanced user inputs," which are the life-cycle cost input values that were set as default values for the analysis by the research team and the Technical Panel. Certain "advanced user inputs" were set for the agency cost component of the life-cycle costs.

- Analysis period – 20 years
- Discount rate – 3.5 percent
- Analysis year – Current calendar year (2004)
- Include salvage value in life-cycle cost analysis – Yes

Other "advanced user inputs" can be altered for the user cost component of the life-cycle cost analysis. The default values are shown below.

- Traffic growth rate – 1.2 percent
- Traffic breakdown by vehicle type
    - Passenger cars – 97 percent
    - Commercial delivery truck – 1 percent
    - Single unit truck – 1 percent
    - 2-S2 trucks (2-axle tractor-semitrailer) – 0.5 percent
    - 3-S2 trucks (3-axle tractor-semitrailer) – 0.5 percent

Schematics of the various vehicle types are shown in figure 5-9. It should be noted that farm equipment should be included in the 2-S2 category for traffic classification. When editing the "advanced user inputs" relating to the user costs, the user also has the ability to set the crash potential rates for each surface type separately. All of these "advanced user inputs" for agency and user costs can be edited and at any time the program can be reset to default values.

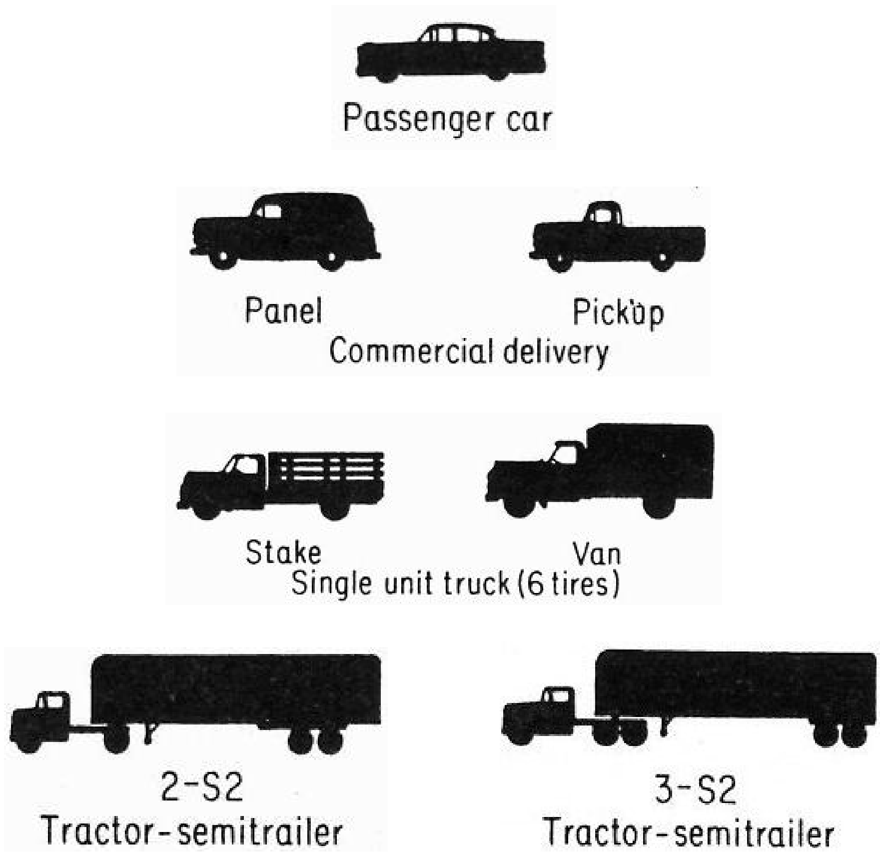


Figure 5-9. Schematics of vehicle type classification.

The step-by-step procedure provided in the software tool closely follows the methodology used in the manual procedure. The setup of the tool allows the user to progress screen by screen to provide the specific information required to determine the appropriate surface type for the given roadway section. Recommendations and guidelines are placed throughout the tool to provide the user with additional direction in selecting appropriate inputs for the given roadway section. In addition, the *Help* portion of the program is linked to the *User's Guide* to provide additional guidance in navigating through and properly using the tool.

The program allows the user to consider any combination of agency costs, user costs, and non-economic factors. In the first steps of the program the user determines the agency and user cost components of the analysis; outputs from this portion include the summary of cost information displayed in table 5-12. All costs in the table are summarized in present worth dollars per mile of roadway based upon the analysis period and discount rate specified in the analysis setup. In addition to the cost summary results, the software also produces a comparison of cumulative costs for the various surface types in the analysis. This plot, which summarizes the cumulative costs over the analysis period, is shown in figure 5-9. Based solely on costs, the most cost-effective surface type is that surface that provides the lowest total cost.

Table 5-12. Sample cost summary results from the automated software tool.

COST SUMMARY RESULTS

AGENCY COST SUMMARY				
	Unit Costs ($/mile) for Different Surface Types			
Cost Type	HMA	Blotter	Gravel	Stabilized Gravel
Initial Cost	$37,000	$7,850	$7,036	$19,716
Maintenance Costs	$55,344	$45,625	$94,752	$141,973
Salvage Value	$20,409	$3,098	$1,768	$9,415
TOTAL AGENCY COSTS	**$71,935**	**$50,376**	**$100,020**	**$152,274**

USER COST SUMMARY				
	Unit Costs ($/mile) for Different Surface Types			
Cost Type	HMA	Blotter	Gravel	Stabilized Gravel
Vehicle Operating Costs (VOC)	$318,226	$370,039	$473,664	$421,851
Crash Costs	$181,670	$145,420	$38,920	$73,430
Total VOC & Crash Costs	$499,896	$515,459	$512,584	$495,281
User Cost Weighting Factor	0.125	0.125	0.125	0.125
TOTAL USER COSTS (Weighted)	**$ 62,487**	**$ 64,432**	**$ 64,073**	**$ 61,910**

TOTAL COST SUMMARY				
TOTAL COST (Agency + User)	**$134,422**	**$114,809**	**$164,093**	**$214,184**

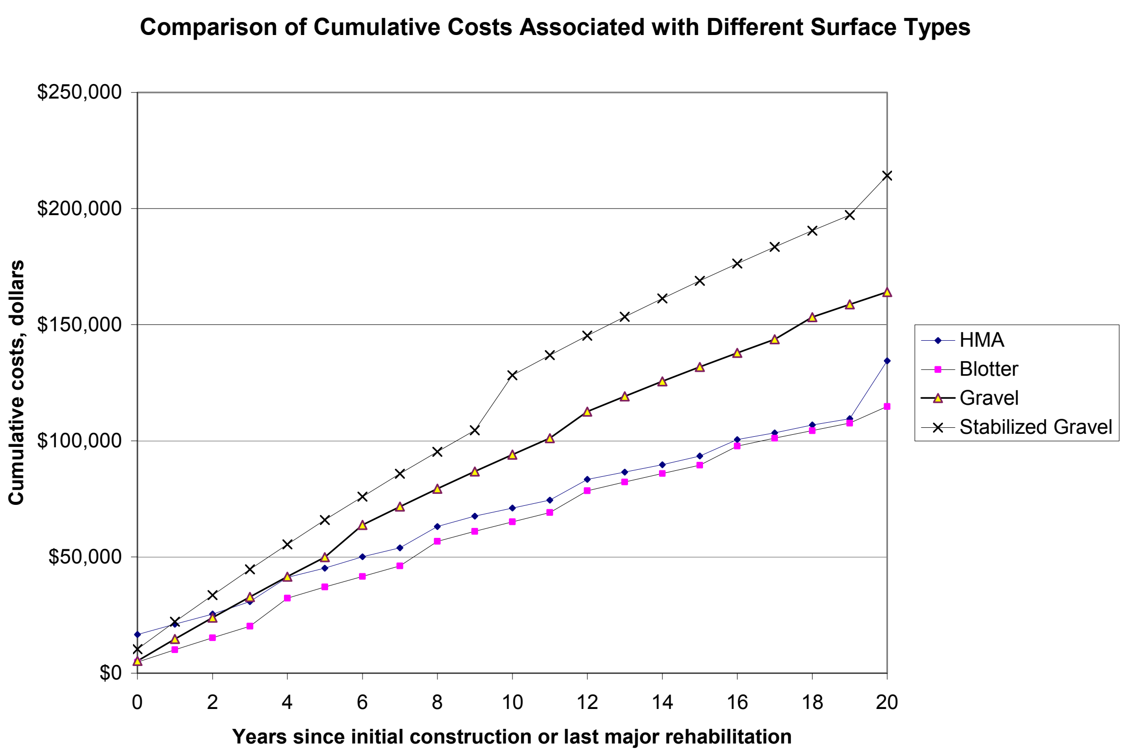


Figure 5-10. Sample comparison of cumulative costs associated with different surface types from the automated software tool.

If a user decides to consider non-economic factors, rating and scoring factors are assigned to all surface types and final scores are calculated and provided in tabular format in the software tool. An example of the output is shown in table 5-13. The surface with the highest overall score is considered the appropriate surface type for the given set of circumstances for the road section. More details about the software tool are provided in the *User's Guide*, which is submitted separately from this report.

Table 5-13. Sample scoring table output from the automated software tool.

Scoring Table for Different Factor Categories									
		Score Calculations for Different Surface Types							
		HMA		Blotter		Gravel		Stabilized Gravel	
Factor Categories	Rating Factor (%)	Scoring Factor	Computed Total Score	Scoring Factor	Computed Total Score	Scoring Factor	Computed Total Score	Scoring Factor	Computed Total Score
Total Cost	55	3	3 x 55/100 = 1.65	4	4 x 55/100 = 2.20	2	2 x 55/100 = 1.10	1	1 x 55/100 = 0.55
Political Issues	25	4	4 x 25/100 = 1.00	3	3 x 25/100 = 0.75	1	1 x 25/100 = 0.25	2	2 x 25/100 = 0.50
Growth Rates	0	4	4 x 0/100 = 0.00	3	3 x 0/100 = 0.00	1	1 x 0/100 = 0.00	2	2 x 0/100 = 0.00
Housing Concentration/ Dust Control	10	4	4 x 10/100 = 0.40	3	3 x 10/100 = 0.30	1	1 x 10/100 = 0.10	2	2 x 10/100 = 0.20
Mail Routes	5	4	4 x 5/100 = 0.20	3	3 x 5/100 = 0.15	1	1 x 5/100 = 0.05	2	2 x 5/100 = 0.10
Industry/Truck	5	4	4 x 5/100 = 0.20	3	3 x 5/100 = 0.15	1	1 x 5/100 = 0.05	2	2 x 5/100 = 0.10
TOTALS	**100**		**3.45**		**3.55**		**1.55**		**1.45**

5.5 Summary

Through literature review and multiple rounds of data assessment, the research team was able to develop appropriate models for agency and user costs for different low volume road surfacing types in South Dakota, and combine these models into a practical methodology to assist in selecting the appropriate surface type for a given roadway section. The methodology can be used by local agencies in South Dakota in either a manual or automated format to provide information needed for making surfacing decisions.

6.0 IMPLEMENTATION RECOMMENDATIONS

Chapter 5 presents the findings and conclusions that were generated from the research work on this project. In this chapter, the research team presents the resulting recommendations that will guide the SDDOT through the implementation of the research results. The following recommendations are presented for consideration by the Technical Panel.

1.0 Select a minimum of three local agencies to test the software and manual procedure prior to distribution of both tools.

The Technical Panel should choose at least three agencies that can test the software tool and manual procedure to verify the validity of the resulting recommendations. Roadway information for specific sections identified by each of the pilot agencies should be tested using each method. Results of the verification activities should be reported to the Technical Panel prior to distribution of the products and should be considered as a supplement to the Train-the-Trainer materials.

2.0 Introduce the potential users of the tools (*Technical Brief* and automated software) to their usefulness with the Train-the-Trainer materials.

- While the tools are relatively simple, the users of these products need to be introduced to the basic procedures and assumptions that accompany each tool prior to its use. The Technical Panel should select a representative to present the results of this project at an upcoming meeting of the South Dakota Association of Counties.

3.0 Promote the use of the automated software tool over the manual procedure whenever possible.

- The manual and automated procedures provide a solid methodology for determining appropriate surface type. However, the default values used in the tools are largely based upon averages calculated from agency data. Therefore, when using the Train-the-Trainer materials to introduce the county superintendents to the project methodology, the instructors should stress the use of section-specific information over the use of the default values as much as possible.

4.0 Distribute an electronic copy of the *User's Guide* for the automated software with each distributed copy of the software tool.

- Whether the software tool is distributed via a download from the web or on a CD, copies of the *User's Guide* should also be made available to all those acquiring copies of the software tool.

5.0 Periodically update the default models used in the analysis so they continue to reflect costs that are reasonable within the local agencies in South Dakota if the tools prove to be useful to local agencies.

- The default models that are incorporated into the *Technical Brief* and spreadsheet tool are based on the maintenance cycles and costs used by the participating counties at the time the study was conducted. These values can be expected to change with time, which may affect the results. For this reason, the SDDOT should make provisions for updating the default models if the tools prove to be useful to local agencies. If the models are updated, snow removal costs should be considered as an additional cost consideration in the models. If the manual approach continues to be used, a revised *Technical Bulletin* should be issued to reflect updated costs.

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APPENDIX A.
LITERATURE REVIEW

Anderson, J., and J. Sessions. 1991. "Managing Low-Volume Road Systems for Intermittent Use." *Transportation Research Record 1291.* Transportation Research Board, Washington, D.C.

Abstract: This paper notes that low-volume roads are often used for short periods of time that are separated by long periods of little or no use. Therefore it is important to have a management strategy to decide which roads should be closed, which should be left open and maintained, and which should be reopened. A mathematical formulation for intermittent road management is given.

Archondo-Callao, R. 1999. "Economic Decision Model for Low-Volume Roads." *Transportation Research Record 1652.* Transportation Research Board, Washington, D.C.

Abstract: This report presents a model developed to improve the decision making process for the development and maintenance of low-volume roads in Africa. The model uses the consumer surplus approach to perform an economic evaluation of road investment options. This model is meant to improve upon the already in place Highway Design and Maintenance Standards Model (HDM-III) by presenting a framework for low-volume unpaved roads. Also contained in this report is a method for estimating roughness from vehicle speeds as roughness is hard to estimate on unpaved roads.

Archondo-Callao, R., D. Méndez-Talavera, and L. Cantarero-Zeas. 2003. "Network-Level Application of Roads Economic Decision Model in Nicaragua." *Transportation Research Record 1819*. Transportation Research Board, Washington D.C.

Abstract: The Roads Economic Design model was developed as a decision-making tool specifically for low-volume roads. This study shows that the development and maintenance of these roads requires a focus on the high uncertainty of model inputs.

Berger, L. and J. Greenstein. 1987. "Simplified Procedures to Manage the Maintenance of Low-Volume Roads." *Transportation Research Record 1106.* Transportation Research Board, Washington, D.C.

Abstract: The study considers maintenance requirements and work activities for stone, natural gravel, and mechanically stabilized base course pavement (no HMA). The required level of work for each activity is analyzed for each road type. Included in this report is an investigation of maintenance costs versus user costs. In order to keep vehicle operating costs (VOCs) at a minimum, the study indicates that the road network must be kept at a nearly as-built condition level.

Bhandari, A., S., Kumares, and C. Sinha. 1979. "Optimal Timing For Paving Low-Volume Gravel Roads." *Transportation Research Record 702.* Transportation Research Board, Washington, D.C.

Abstract: This paper examines the economics of upgrading low-volume gravel roads with particular emphasis on construction postponement. Simplified expressions of a break-even analysis are developed to determine both the break-even year and the optimal year in which to pave a given gravel road.

Brown, M., S. Mercier, and Y. Provencher. "Road Maintenance with Opti-Grade: Maintaining Road Networks to Achieve the Best Value." *Transportation Research Record 1819.* Transportation Research Board, Washington, D.C.

Abstract: The Forest Engineering Research Institute of Canada (FERIC) developed the Opti-Grade tool to deal with the lack of information on the condition of Canada's unpaved road network. Sample values for annual maintenance cost per kilometer are provided.

Cook, C.C. 1987. "Evaluating Alternative Maintenance Strategies for Low-Volume Roads in Sub-Saharan Africa." *Transportation Research Record 1106.* Transportation Research Board, Washington, D.C.

Abstract: This report investigates the justification of maintenance on low-volume roads and takes into consideration the agricultural growth of the region. The methodology follows user cost savings with the agricultural value added.

DiBiaso, M. 2002. "When Should I Pave a Gravel Road?" *University of New Hampshire Technology Newsletter.* University of New Hampshire T^2 Center, Durham, NH.

Abstract: Among the topics discussed in this newsletter are the pros and cons of unpaved roads, safety and design of roadways, and relative costs of various road surfaces. The article also gives recommendations for when unpaved roads should be paved.

Eck, R.W. 1987. "A Microcomputer Program to Assist in Low-Volume Road Rehabilitation Decision Making." *Transportation Research Record 1128.* Transportation Research Board, Washington, D.C.

Abstract: This paper focuses on a guided decision-making tool to determine whether a road is a candidate for upgrading. Previous studies cited in this paper predicted surface deterioration, rehabilitation costs, maintenance costs, and road user costs. The paper argues that although low-volume roads only account for 8 percent of total highway travel, they are important as they make up more than two-thirds of public highway mileage.

Faiz, A., and E. Staffini. 1979. "Engineering Economics of the Maintenance of Earth and Gravel Roads." *Transportation Research Record 702.* Transportation Research Board, Washington, D.C.

Abstract: This paper presents a methodology for the economic evaluation of maintenance programs for unpaved roads with an ADT of less than 250. The technique draws heavily on road deterioration and user cost relationships. The economic analysis used in the methodology permits the differentiation of benefits, in the form of vehicle operating cost savings, between routine and periodic maintenance.

Franklin Regional Council of Governments. 2001. *Answers to Frequently Asked Questions About Gravel Roads*. Franklin Regional Council of Governments, Greenfield, MA.

Abstract: This document gives information about gravel roads including roadway structure, maintenance, traffic, regulatory, environmental, and general concerns. Of specific importance is the section regarding the application of Calcium Chloride as a stabilizer.

Gannon, C., and J. Lebo. "Design and Evaluation of Very Low-Volume Rural Roads in Developing Countries." *Transportation Research Record 1652.* Transportation Research Board, Washington, D.C.

Abstract: This paper makes an economic evaluation of rural roads. Notable among the points discussed is that of the producer surplus as taken into account by the HDM versus the consumer surplus. With the producer surplus the benefits are estimated with productive uses whereas with the consumer surplus the benefits are derived from a reduction in transportation cost.

Givens, J.S. 2003. "Rural Rustic Roads in Virginia: Implementation of Program Guidelines and Pilot Projects." *Transportation Research Record 1819*. Transportation Research Board, Washington, D.C.

Abstract: Virginia has passed legislation to pave low-density roads in a manner to leave trees, vegetation, side slopes and open drainage as undisturbed as possible. The program will use the existing alignment of the unpaved roads to preserve the character of the area. Estimates for normal improvements are provided in a cost comparison.

Harral, C.G., and S.K. Agarwal. 1975. "Highway Design Standards Study." *Transportation Research Board, Special Report 160*. Transportation Research Board, Washington, D.C.

Abstract: This paper presents the background of a study evaluating alternative design and maintenance strategies for low-volume roads. Of importance is the section on vehicle operating costs in which the paper discusses the significant effect of roughness on every vehicle operating cost but depreciation.

Jahren, C.T. 2001. *Best Practices For Maintaining And Upgrading Aggregate Roads in Australia And New Zealand*. Staff Paper, P2002-01. Minnesota Department of Transportation, Maplewood, MN.

Abstract: This report utilizes comparisons between Australia, New Zealand and the United States to provide recommendations on the design and upgrade of aggregate roads. The study touches on surfacing and maintenance. One of the findings is that wet maintenance yields superior results to dry maintenance, with only a very slight increase in cost. Based upon traffic studies, the author considers 200 vehicles per day to be the upper limit for an aggregate road.

Jones, T.E., and Y. Promprasith. 1991. "Maintenance of Unpaved Roads in Wet Climates." *Transportation Research Record 1291.* Transportation Research Board, Washington, D.C.

Abstract: This paper discusses a research project on gravel roads in Thailand and in other wet regions. It explores the relative performance of motor graders and tractor-towed graders and concludes that the tractor-towed graders are more cost effective and achieve the same reductions in roughness as motor graders. Of importance in this paper are the performance models for IRI and Rutting Index.

Kerali, H.G.R. 2000. *HDM-4 (Highway Development & Management), Volume One: Overview of HDM-4*. The World Road Association (PIARC), France.

Abstract: Various versions of the HDM model have been used to justify increased road maintenance and rehabilitation budgets in many countries. The additional capabilities covered in this version include traffic congestion effects, cold climate effects, a wider range of pavement types and structures, road safety and environmental effects. Also included in this model is the effect of road condition on vehicle operating costs. An example of the use of this model is provided.

McLean, J. 1995. "Low Volume Roads in Australia." *Transportation Research Circular, Volume 446*. Transportation Research Board, Washington, D.C.

Abstract: This report provides a discussion of the various issues facing low-volume roads in Australia. The topics include the design of the pavement and cross-section, emerging issues, and recent developments including the results of a seal width study.

National Cooperative Highway Research Program (NCHRP). 2000. "Methodology to Improve Pavement-Investment Decisions." *National Cooperative Highway Research Program, Research Results Digest, No. 246.* Transportation Research Board, Washington, D.C.

Abstract: This report identifies the relationships between user costs and pavement roughness and presents a new index for summarizing pavement roughness. Of note in this report is the life-cycle cost analysis methodology that considers pavement roughness and user costs.

Paige-Green, P. 1998. "Materials for Sealed Low-Volume Roads." *Transportation Research Record 1652*. Transportation Research Board, Washington, D.C.

Abstract: This study shows that sealing roads with a bituminous surfacing is a cost-effective method to upgrade low-volume roads with traffic counts as low as 50 vehicles per day. The study investigates the effects of base course properties and provides recommendations for design materials to be used as a base course.

Pienaar, P.A., and A.T. Visser. 1995. "Management of Tertiary Road Networks in Rural Areas of South Africa." *Sixth International Conference on Low-Volume Roads*. Transportation Research Board, Washington, D.C.

Abstract: This paper presents a methodology for providing optimal tertiary road networks. Included are techniques to optimize the layout of tertiary road networks, techniques to estimate traffic volumes, methodology to identify maintenance and upgrading projects on tertiary roads, and project evaluation and prioritization methodology.

Queiroz, C.A.V., P.S.M. Coelho, J.P. Magalhaes, and N.F. Robertson. 1987. "An Optimal Design Method To Rehabilitate Low-Volume Asphaltic Roads." *Transportation Research Record 1106.* Transportation Research Board, Washington, D.C.

Abstract: The pavement prediction models discussed in this paper are used to develop a design method that selects the optimal rehabilitation strategy over a defined analysis period. The design method can be used as a project-level pavement management tool.

Road Commission for Oakland County. 2000. *Gravel Roads*. Road Commission for Oakland County, Beverly Hills, MI.

Abstract: This pamphlet provides a reader-friendly look into the importance of gravel roads and emphasizes the importance of maintenance on drainage and dust control.

Sebaaly, P.E., R. Siddharthan, and D. Huft. 2003. "Impact of Heavy Vehicles on Low-Volume Roads." *Transportation Research Record 1819*. Transportation Research Board, Washington D.C.

Abstract: A recent study sponsored by the South Dakota Department of Transportation explored the significance of agricultural equipment on low-volume gravel and blotter roads. Variables considered in this study included the season, load level, thickness of crushed aggregate base, and soil type. Analysis of the collected data showed that certain agricultural equipment can be significantly more damaging to low-volume roads than an 18,000-lb single-axle truck.

Selim, A.A., O. K. Skorseth, and R. Muniandy. 2003. "Long-Lasting Gravel Roads: Case Study from the United States." *Transportation Research Record 1819.* Transportation Research Board, Washington D.C.

Abstract: A low-volume gravel road in Hand County, South Dakota, was constructed in 1963 and had not been rehabilitated or reconstructed at the time this paper was written. It has shown excellent performance while carrying a significant amount of truck traffic. A notable conclusion states that, "it is not the surface course that counts. It is the base and the subbase." This suggests the importance of the lower layers of low-volume gravel roads and their significance in the performance of the roadway.

Skorseth, K. 2003. "Serving Rocky Roads." *Roads and Bridges*, *Volume 41, No. 6.* Scranton Gillette Communications, Des Plaines, IL.

Abstract: Gravel roadways in the United States are an important link to many areas otherwise inaccessible. While the cost of paving cannot be justified, proper maintenance can be used to keep these roads in usable condition. Maintaining the cross section and using a quality mix are very important in this process.

Tervala, J. 1995. "Low-Volume Roads in Finland." *Sixth International Conference on Low-Volume Roads*. Transportation Research Board, Washington, D.C.

Abstract: This paper states that emulsion gravel is a common pavement type for low-volume roads in Finland, and due to ease of maintenance it is beneficial on low-volume roads with ADT from 350 to 1,000. Of note is the section on benefit/cost ratios. This report concludes that upgrading low-volume roads can rarely be justified with a cost-benefit analysis. It is also reported that improving geometry may lead to an increase in speed and consequently an increase in the number of accidents.

Van Zyl, G.D., A.T. Visser, and J.A. du Plessis. 1995. "Guidelines for Structural Design of Low-Volume Rural Roads in Southern Africa." *Sixth International Conference on Low-Volume Roads*. Transportation Research Board, Washington, D.C.

Abstract: This paper develops new standards for low-volume roads. Using traditional standards, upgrading roads would only be warranted if the average daily traffic exceeded

400. This report provides these new standards that incorporate lower volume roads in their design parameters.

Veeraragavan, A., and K.B.R. Reddy. 2003. "Application of Highway Development and Management Tool for Low-Volume Roads." *Transportation Research Record 1819*. Transportation Research Board, Washington D.C.

Abstract: This study applies the Highway Development and Management Tool (HDM-4) to low-volume roads to maximize the net present value and minimize the costs of maintenance. The project used a design period of 20 years and used a discount rate of 12 percent. The study showed that the application of HDM-4 could be used to manage low-volume roads effectively.

Visser, A.T., and W.R. Hudson. 1983. "Performance, Design, and Maintenance Relationships for Unpaved Low-Volume Roads." *Transportation Research Record 898.* Transportation Research Board, Washington, D.C.

Abstract: This paper gives an approach for evaluating unpaved road performance and deterioration based on an extensive study in Brazil. Equations for predicting roughness, rut depth, and gravel loss are developed. The study found that traffic has the greatest influence on regraveling and blading strategies as well as on the total cost of unpaved roads.

Walker, D.M., and P. Scherer. 1987. "Roadway Management for Local Roads." *Transportation Research Record 1106.* Transportation Research Board, Washington, D.C.

Abstract: This paper provides an evaluation tool to balance the dilemma between providing an improved level of service and reducing taxes. It evaluates the overall condition of roadways in light of the goals and future needs of the municipality. Early results indicate that the tool has enabled local officials to better understand the need for improvements, establish objective priorities, and justify significant increases in the local road improvement budgets. Included is a pertinent roadway condition form used to assess general roadway surface condition.

Walzer, N., and D. L. Chicoine. 1987. "Financing and Maintaining Low-Volume Roads in the Midwestern United States." *Transportation Research Record 1106.* Transportation Research Board, Washington, D.C.

Abstract: This paper discusses the uses of rural roads by the farm sector, the condition of roads and bridges, the main revenue sources that fund rural roads, and the policy options to address the rebuilding of rural road systems. The paper concludes that the magnitude of the costs of upgrading the system to acceptable levels is so large that local rural governments do not have the fiscal capacity to make needed improvements without financial help from states and the federal government.

APPENDIX B.
SURVEY FORMS FROM INITIAL MAILING

Hot-Mix Asphalt (HMA) Roads

Instructions

Please complete this form by providing contact information and completing each line in the table. Each line lists a specific set of criteria that is needed for the study. If you have information such as road structure, construction cost, and maintenance information for a pavement section in your county that meets the listed criteria, check the "Yes" box on that line. If not, please check "No". If you checked "Yes" for a given criteria, also provide the name of the road and indicate whether the given section you have in mind has a low or high truck traffic volume by circling the appropriate traffic level. The following terms are provided to assist in completing the table.

- **Subgrade** – A subgrade ranking of poor refers to a road that has had rutting or settling problems or is (or should be) posted due to poor subgrade conditions. If a road does not have these problems, the subgrade is considered good.
- **ADT** – Average daily traffic (ADT) in one direction.
- **Truck Traffic Level** – A low truck traffic level refers to an average daily truck traffic level of less than 10 percent of the overall traffic volume. A high truck traffic level refers to an average daily truck traffic level of greater than 10 percent of the overall traffic volume.

Name: _________________________
County: _______________________
Phone No: ______________________ **Fax No:** ____________________ **Email:** ____________________

Criteria	Terrain	Subgrade	ADT	No	Yes	Road Name	Truck Traffic Level
1	Flat	Good	< 125				High / Low
2	Flat	Good	125 - 250				High / Low
3	Flat	Good	251 - 400				High / Low
4	Flat	Good	> 400				High / Low
5	Flat	Poor	< 125				High / Low
6	Flat	Poor	125 - 250				High / Low
7	Flat	Poor	251 - 400				High / Low
8	Flat	Poor	> 400				High / Low
9	Rolling	Good	< 125				High / Low
10	Rolling	Good	125 - 250				High / Low
11	Rolling	Good	251 - 400				High / Low
12	Rolling	Good	> 400				High / Low
13	Rolling	Poor	< 125				High / Low
14	Rolling	Poor	125 - 250				High / Low
15	Rolling	Poor	251 - 400				High / Low
16	Rolling	Poor	> 400				High / Low
17	Mountainous	Good	< 125				High / Low
18	Mountainous	Good	125 - 250				High / Low
19	Mountainous	Good	251 - 400				High / Low
20	Mountainous	Good	> 400				High / Low
21	Mountainous	Poor	< 125				High / Low
22	Mountainous	Poor	125 - 250				High / Low
23	Mountainous	Poor	251 - 400				High / Low
24	Mountainous	Poor	> 400				High / Low

Blotter Roads

Instructions

Please complete this form by providing contact information and completing each line in the table. Each line lists a specific set of criteria that is needed for the study. If you have information such as road structure, construction cost, and maintenance information for a pavement section in your county that meets the listed criteria, check the "Yes" box on that line. If not, please check "No". If you checked "Yes" for a given criteria, also provide the name of the road and indicate whether the given section you have in mind has a low or high truck traffic volume by circling the appropriate traffic level. The following terms are provided to assist in completing the table.

- **Subgrade** – A subgrade ranking of poor refers to a road that has had rutting or settling problems or is (or should be) posted due to poor subgrade conditions. If a road does not have these problems, the subgrade is considered good.
- **ADT** – Average daily traffic (ADT) in one direction.
- **Truck Traffic Level** – A low truck traffic level refers to an average daily truck traffic level of less than 10 percent of the overall traffic volume. A high truck traffic level refers to an average daily truck traffic level of greater than 10 percent of the overall traffic volume.

Name: ________________________
County: ______________________
Phone No: _____________________ **Fax No:** ___________________ **Email:** ___________________

Criteria	Terrain	Subgrade	ADT	No	Yes	Road Name	Truck Traffic Level
1	Flat	Good	< 125				High / Low
2	Flat	Good	125 - 250				High / Low
3	Flat	Good	251 - 400				High / Low
4	Flat	Good	> 400				High / Low
5	Flat	Poor	< 125				High / Low
6	Flat	Poor	125 - 250				High / Low
7	Flat	Poor	251 - 400				High / Low
8	Flat	Poor	> 400				High / Low
9	Rolling	Good	< 125				High / Low
10	Rolling	Good	125 - 250				High / Low
11	Rolling	Good	251 - 400				High / Low
12	Rolling	Good	> 400				High / Low
13	Rolling	Poor	< 125				High / Low
14	Rolling	Poor	125 - 250				High / Low
15	Rolling	Poor	251 - 400				High / Low
16	Rolling	Poor	> 400				High / Low
17	Mountainous	Good	< 125				High / Low
18	Mountainous	Good	125 - 250				High / Low
19	Mountainous	Good	251 - 400				High / Low
20	Mountainous	Good	> 400				High / Low
21	Mountainous	Poor	< 125				High / Low
22	Mountainous	Poor	125 - 250				High / Low
23	Mountainous	Poor	251 - 400				High / Low
24	Mountainous	Poor	> 400				High / Low

Gravel Surfaced Roads

Instructions

Please complete this form by providing contact information and completing each line in the table. Each line lists a specific set of criteria that is needed for the study. If you have information such as road structure, construction cost, and maintenance information for a pavement section in your county that meets the listed criteria, check the "Yes" box on that line. If not, please check "No". If you checked "Yes" for a given criteria, also provide the name of the road and indicate whether the given section you have in mind has a low or high truck traffic volume by circling the appropriate traffic level. The following terms are provided to assist in completing the table.

- **Subgrade** – A subgrade ranking of poor refers to a road that has had rutting or settling problems or is (or should be) posted due to poor subgrade conditions. If a road does not have these problems, the subgrade is considered good.
- **ADT** – Average daily traffic (ADT) in one direction.
- **Truck Traffic Level** – A low truck traffic level refers to an average daily truck traffic level of less than 10 percent of the overall traffic volume. A high truck traffic level refers to an average daily truck traffic level of greater than 10 percent of the overall traffic volume.

Name: ___________________________
County: _________________________
Phone No: ________________________ **Fax No:** _____________________ **Email:** ______________________

Criteria	Terrain	Subgrade	ADT	No	Yes	Road Name	Truck Traffic Level
1	Flat	Good	< 125				High / Low
2	Flat	Good	125 - 250				High / Low
3	Flat	Good	251 - 400				High / Low
4	Flat	Good	> 400				High / Low
5	Flat	Poor	< 125				High / Low
6	Flat	Poor	125 - 250				High / Low
7	Flat	Poor	251 - 400				High / Low
8	Flat	Poor	> 400				High / Low
9	Rolling	Good	< 125				High / Low
10	Rolling	Good	125 - 250				High / Low
11	Rolling	Good	251 - 400				High / Low
12	Rolling	Good	> 400				High / Low
13	Rolling	Poor	< 125				High / Low
14	Rolling	Poor	125 - 250				High / Low
15	Rolling	Poor	251 - 400				High / Low
16	Rolling	Poor	> 400				High / Low
17	Mountainous	Good	< 125				High / Low
18	Mountainous	Good	125 - 250				High / Low
19	Mountainous	Good	251 - 400				High / Low
20	Mountainous	Good	> 400				High / Low
21	Mountainous	Poor	< 125				High / Low
22	Mountainous	Poor	125 - 250				High / Low
23	Mountainous	Poor	251 - 400				High / Low
24	Mountainous	Poor	> 400				High / Low

Stabilized Gravel Surfaced Roads

Instructions

Please complete this form by providing contact information and completing each line in the table. Each line lists a specific set of criteria that is needed for the study. If you have information such as road structure, construction cost, and maintenance information for a pavement section in your county that meets the listed criteria, check the "Yes" box on that line. If not, please check "No". If you checked "Yes" for a given criteria, also provide the name of the road and indicate whether the given section you have in mind has a low or high truck traffic volume by circling the appropriate traffic level. The following terms are provided to assist in completing the table.

- **Subgrade** – A subgrade ranking of poor refers to a road that has had rutting or settling problems or is (or should be) posted due to poor subgrade conditions. If a road does not have these problems, the subgrade is considered good.
- **ADT** – Average daily traffic (ADT) in one direction.
- **Truck Traffic Level** – A low truck traffic level refers to an average daily truck traffic level of less than 10 percent of the overall traffic volume. A high truck traffic level refers to an average daily truck traffic level of greater than 10 percent of the overall traffic volume.

Name: ________________________

County: ________________________

Phone No: ______________________ **Fax No:** ____________________ **Email:** ____________________

Criteria	Terrain	Subgrade	ADT	No	Yes	Road Name	Truck Traffic Level
1	Flat	Good	< 125				High / Low
2	Flat	Good	125 - 250				High / Low
3	Flat	Good	251 - 400				High / Low
4	Flat	Good	> 400				High / Low
5	Flat	Poor	< 125				High / Low
6	Flat	Poor	125 - 250				High / Low
7	Flat	Poor	251 - 400				High / Low
8	Flat	Poor	> 400				High / Low
9	Rolling	Good	< 125				High / Low
10	Rolling	Good	125 - 250				High / Low
11	Rolling	Good	251 - 400				High / Low
12	Rolling	Good	> 400				High / Low
13	Rolling	Poor	< 125				High / Low
14	Rolling	Poor	125 - 250				High / Low
15	Rolling	Poor	251 - 400				High / Low
16	Rolling	Poor	> 400				High / Low
17	Mountainous	Good	< 125				High / Low
18	Mountainous	Good	125 - 250				High / Low
19	Mountainous	Good	251 - 400				High / Low
20	Mountainous	Good	> 400				High / Low
21	Mountainous	Poor	< 125				High / Low
22	Mountainous	Poor	125 - 250				High / Low
23	Mountainous	Poor	251 - 400				High / Low
24	Mountainous	Poor	> 400				High / Low

APPENDIX C.
SURVEY FORMS FROM SECOND MAILING

Survey Form Instructions

The following listing provides a detailed description of the information that is requested on the survey forms. These instructions were developed to aid in the correct completion of the forms. If written records for any sections do not exist, your best estimate will suffice. If information is not known please indicate "Not Known" or if the question does not seem applicable to you, please indicate this by using "NA".

Road Name – The road name is the name that corresponds to the section information we need. You provided us with this road name on the initial participation survey.

Surface – The surface of the roadway refers to the pavement type (i.e. HMA, blotter, gravel or stabilized gravel).

Terrain – The terrain of the roadway refers to the topography of the roadway and the land surrounding it.

Subgrade – The subgrade is classified as either good or poor. A poor subgrade refers to a road that has had rutting or settling problems or has spring load restrictions due to poor subgrade. If a road does not have these problems, the subgrade is considered good.

ADT Level – The ADT level is the average daily traffic in one direction. There are four ADT levels: less than 125 vehicles per day, 125 to 250 vehicles per day, 250 to 400 vehicles per day, and more than 400 vehicles per day.

Truck Traffic Level – The truck traffic level is classified as either low or high based upon spring or fall traffic. A low truck traffic level refers to an average daily truck traffic level of less than 10 percent of the overall traffic volume. A high truck traffic level refers to an average daily truck traffic level of greater than 10 percent of the overall traffic volume.

Location of Road – The milepost of the roadway, to/from locations, distance and direction from a reference marker, or comparable description should be provided. The description must provide enough information that the section can be located in the field if necessary.

Length of Road Section – The approximate length of the road section in terms of miles or feet should be indicated.

Pavement Thickness – The thickness of each layer of the existing road should be described in terms of inches. If one of the layers does not exist indicate this by using "NA". If you know the layer exists but you are unsure of the thickness indicate this by using "Not Known" or estimate the thickness.

Initial Pavement Construction Cost or Last Rehabilitation Cost – Cost information should be provided for either the initial pavement construction or for the last major rehabilitation. The information can be recorded as either total cost in dollars or the construction cost per mile of pavement for the section.

Age – The age of the pavement should be based upon either the initial construction or the last rehabilitation date and should coincide with whether initial pavement construction cost or last rehabilitation cost was provided earlier on the form.

Maintenance Treatment Table – The table lists various potential maintenance treatments that are used on a given surface type. Indicate all of the treatments that were used by your agency on the given road by circling "Yes" in the ***Was this treatment used on this road?*** column. There is also an additional row that allows you to write in a treatment type if you used a treatment that is not provided in the table. For each treatment used on the pavement, also provide information on the ***Frequency of use*** of the treatment based upon the average number of times per year the treatment is used or the number of years between use (i.e.

application cycle). The ***Cost*** of the treatment should be recorded in total cost per application/use or the cost of the application per mile of pavement. If there are multiple applications of a treatment, record the average cost of the treatment. The ***Approximate Condition of the Pavement at Time of Application*** is also needed. The condition should be estimated on a 1 to 5 scale as follows.

- **5 – Excellent** (No/minimal distress on pavement. Pavement provides an excellent driving surface.)
- **4 – Very Good** (Small amount of distress on pavement. Pavement still provides a good driving surface.)
- **3 – Good** (Large portions of pavement contain distress. The roadway still provides an adequate driving surface.)
- **2 – Fair** (Substantial distress over pavement section which slows travel.)
- **1 – Poor** (Multiple distresses on majority of pavement, which severely impedes travel.)

Number of Years until Major Rehabilitation – Provide the number of years until the roadway will need some type of major rehabilitation (i.e. major resurfacing of a HMA road, rebuilding of a gravel road, etc.)

Posted Speed Limit – The posted or known speed limit should be provided in miles per hour (mph).

Distance to Aggregate Source – The distance to an aggregate source should be provided in terms of the approximate number of miles from the roadway location to an appropriate source of aggregate that could be use in maintaining or rehabilitating the roadway.

Aggregate Type – The aggregate type should be indicated as either gravel or crushed stone depending upon the type of aggregate used for the construction of the road.

Road Located in Growing Area – Indicate whether the road is located in an area with a growing population by circling either "Yes" or "No".

Housing Density – The housing density should be indicated as either high or low. High housing density refers to a large concentration of housing on the specified roadway such as subdivisions or multiple residences located closely to one another. Low housing density refers to very few residential buildings along the given roadway.

Included on the Stabilized Gravel Form Only:

Type of Stabilization – The type of stabilization should indicate the type of material used to provide stabilization of the subgrade (i.e. cement, lime, etc.).

Percentage of Stabilizer – The percentage of stabilizer should indicate the targeted percentage of stabilizer added to the subgrade by weight.

Depth of Stabilization – The depth of stabilization should indicate the average depth of the stabilization performed in units of inches.

South Dakota Local Roads HMA Survey Form

Your response to our initial survey indicated that you have information available for a road section in your county that meets the following criteria.

Road Name:	Rd. #39	**Subgrade:**	Good
Surface:	HMA	**ADT Level:**	< 125
Terrain:	Flat	**Truck Traffic Level:**	Low

Please assure that the following contact information is correct. Also, please provide the following information regarding the specified road section. Please refer to the survey form instructions for a detailed explanation of all headings included on this survey form.

Name: Ron Schulte **County:** Turner **Phone No:** 605.297.3404

Location of Road: ______________________________

Length of Road Section: ________ miles **OR** ________ feet

Pavement Thickness:

***HMA Thickness*:** ________ inches ***Granular Base*:** ________ inches

Initial Pavement Construction Cost or Last Rehabilitation Cost:

$______________ **OR** ______________ $/Mile

Age: ________ years

Maintenance Treatments	Was the treatment used on this road?	Frequency of use	Cost Per Application	Approximate Condition at Time of Application (1 to 5 scale)
Crack Seal	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Seal Coat	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Overlay *(Thickness: ___in.)*	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Striping and Marking	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Annual Maintenance (Patching)	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Mill and Overlay *(Thickness: ___in.)*	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Other__________		________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	

Number of years until next rehabilitation: _____years **Posted Speed Limit:** ________ mph

Distance to an Aggregate Source: ________ miles **Aggregate Type:** Gravel / Crushed Stone

Located in area with growing population: Yes / No **Housing Density:** High / Low

South Dakota Local Roads Blotter Survey Form

Your response to our initial survey indicated that you have information available for a road section in your county that meets the following criteria.

Road Name:	Rd. #23	**Subgrade:**	Good
Surface:	Blotter	**ADT Level:**	< 125
Terrain:	Flat	**Truck Traffic Level:**	Low

Please assure that the following contact information is correct. Also, please provide the following information regarding the specified road section. Please refer to the survey form instructions for a detailed explanation of all headings included on this survey form.

Name: Ron Schulte **County:** Turner **Phone No:** 605.297.3404

Location of Road: ____________________

Length of Road Section: ________ miles **OR** ________ feet

Initial Pavement Construction Cost or Last Rehabilitation Cost:

$______________ **OR** ______________ $/Mile

Age: ________ years

Maintenance Treatments	Was the treatment used on this road?	Frequency of use	Cost Per Application	Approximate Condition at Time of Application (1 to 5 scale)
Seal Coat	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Mill and Overlay *(Thickness: ____ in.)*	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Overlay *(Thickness: ____ in.)*	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Striping and Marking	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Annual Maintenance	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Process in place, add aggregate, and reblot	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Other___________		________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	

Number of years until next rehabilitation: _____ years

Posted Speed Limit: ________ mph

Distance to an Aggregate Source: ________ miles

Aggregate Type: Gravel / Crushed Stone

Located in area with growing population: Yes / No

Housing Density: High / Low

South Dakota Local Roads Gravel Survey Form

Your response to our initial survey indicated that you have information available for a road section in your county that meets the following criteria.

Road Name:	Rd. #40	**Subgrade:**	Good
Surface:	Gravel	**ADT Level:**	< 125
Terrain:	Flat	**Truck Traffic Level:**	Low

Please assure that the following contact information is correct. Also, please provide the following information regarding the specified road section. Please refer to the survey form instructions for a detailed explanation of all headings included on this survey form.

Name: Ron Schulte **County:** Turner **Phone No:** 605.297.3404

Location of Road: ______________________________

Length of Road Section: ________ miles **OR** ________ feet

Pavement Thickness:
***Gravel Thickness*:** ________ inches

Initial Pavement Construction Cost or Last Rehabilitation Cost:

$______________ **OR** ______________ $/Mile

Age: ________ years

Maintenance Treatments	Was the treatment used on this road?	Frequency of use	Cost Per Application	Approximate Condition at Time of Application (1 to 5 scale)
Blading	Yes / No	________ Times / year **OR** _____ Years between use	________ $/Use **OR** _____ $/Use/Mile	
Regravel	Yes / No	________ Times / year **OR** _____ Years between use	________ $/Use **OR** _____ $/Use/Mile	
Annual Maintenance	Yes / No	________ Times / year **OR** _____ Years between use	________ $/Use **OR** _____ $/Use/Mile	
Reclaiming	Yes / No	________ Times / year **OR** _____ Years between use	________ $/Use **OR** _____ $/Use/Mile	
Reshape cross section	Yes / No	________ Times / year **OR** _____ Years between use	________ $/Use **OR** _____ $/Use/Mile	
Other__________		________ Times / year **OR** _____ Years between use	________ $/Use **OR** _____ $/Use/Mile	

Number of years until next rehabilitation: _____years **Posted Speed Limit:** ________mph

Distance to an Aggregate Source: ________miles **Aggregate Type:** Gravel / Crushed Stone

Located in area with growing population: Yes / No **Housing Density:** High / Low

South Dakota Local Roads Stabilized Gravel Survey Form

Your response to our initial survey indicated that you have information available for a road section in your county that meets the following criteria.

Road Name:	Rd. #37	**Subgrade:**	Good
Surface:	Stabilized Gravel	**ADT Level:**	< 125
Terrain:	Flat	**Truck Traffic Level:**	Low

Please assure that the following contact information is correct. Also, please provide the following information regarding the specified road section. Please refer to the survey form instructions for a detailed explanation of all headings included on this survey form.

Name: Ron Schulte **County:** Turner **Phone No:** 605.297.3404

Location of Road: ______________________________

Length of Road Section: ________ miles **OR** ________ feet

Pavement Thickness:

***Gravel Thickness*:** ________ inches

Initial Pavement Construction Cost or Last Rehabilitation Cost:

$______________ **OR** ______________ $/Mile

Age: ________ years

Maintenance Treatments	Was the treatment used on this road?	Frequency of use	Cost Per Application	Approximate Condition at Time of Application (1 to 5 scale)
Dust control	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Blading	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Regravel	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Reshape cross section	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Annual Maintenance	Yes / No	________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	
Other__________		________ Times / year **OR** ______ Years between use	________ $/Use **OR** ______ $/Use/Mile	

Number of years until next rehabilitation: _____years **Posted Speed Limit:** ________ mph

Distance to an Aggregate Source: ________ miles **Aggregate Type:** Gravel / Crushed Stone

Located in area with growing population: Yes / No **Housing Density:** High / Low

Type of Stabilizer:________ **Percentage of Stabilizer:** ________ **Depth of Stabilization:** _____in.

APPENDIX D.
STATISTICAL ANALYSIS RESULTS

All HMA Data

```
      *** Linear Model ***

Call: lm(formula = Agency.LCC ~ ADT, data = HMA, na.action = na.exclude)
Residuals:
    Min     1Q Median    3Q   Max
 -44646 -11230  -2864 12413 50797

Coefficients:
                 Value Std. Error    t value   Pr(>|t|)
(Intercept) 58119.2582  3786.8574    15.3476     0.0000
        ADT    32.1764     3.8470     8.3641     0.0000

Residual standard error: 18820 on 35 degrees of freedom
Multiple R-Squared: 0.6665
F-statistic: 69.96 on 1 and 35 degrees of freedom, the p-value is 7.288e-010
```

Using Cook's Distance to check for outliers or data that is skewing the regression, 2 data points were determined to be outliers and were removed from the linear regression. The results of the regression are shown below.

```
      *** Linear Model ***

Call: lm(formula = Agency.LCC ~ ADT, data = HMA, na.action = na.exclude)
Residuals:
    Min     1Q Median    3Q   Max
 -28854 -11128  -3103 12033 50495

Coefficients:
                 Value Std. Error    t value   Pr(>|t|)
(Intercept) 58197.7159  3658.4472    15.9078     0.0000
        ADT    32.4968     5.7234     5.6778     0.0000

Residual standard error: 16530 on 33 degrees of freedom
Multiple R-Squared: 0.4942
F-statistic: 32.24 on 1 and 33 degrees of freedom, the p-value is 2.493e-006
```

=> With 95% confidence we can reject the null hypothesis (that the coefficients of the intercept and ADT are zero) and estimate the coefficients for the intercept and ADT to be 58197.72 and 32.50, respectively.

All Blotter Data

```
      *** Linear Model ***

Call: lm(formula = Agency.LCC ~ ADT, data = Blotter, na.action = na.exclude)
Residuals:
    Min     1Q Median    3Q   Max
 -18885 -10486  -6332 14070 34025

Coefficients:
                 Value Std. Error    t value   Pr(>|t|)
(Intercept) 38494.3475  5248.0170     7.3350     0.0000
        ADT    28.9695    18.3899     1.5753     0.1283

Residual standard error: 15340 on 24 degrees of freedom
Multiple R-Squared: 0.09371
F-statistic: 2.482 on 1 and 24 degrees of freedom, the p-value is 0.1283
```

Using Cook's Distance to check for outliers or data that is skewing the regression, 1 data point was determined to be an outlier and was removed from the linear regression. The results of the regression are shown below.

```
*** Linear Model ***

Call: lm(formula = Agency.LCC ~ ADT, data = Blotter, na.action = na.exclude)
Residuals:
    Min    1Q Median   3Q   Max
 -19969 -8274  -2399 5558 34777

Coefficients:
                 Value Std. Error    t value   Pr(>|t|)
(Intercept) 28983.0813  4835.1500     5.9942     0.0000
        ADT    85.4778    19.0290     4.4920     0.0002

Residual standard error: 12990 on 24 degrees of freedom
Multiple R-Squared: 0.4567
F-statistic: 20.18 on 1 and 24 degrees of freedom, the p-value is 0.0001512
```

=> With 95% confidence we can reject the null hypothesis (that the coefficients of the intercept and ADT are zero) and estimate the coefficients for the intercept and ADT to be 28983.08 and 85.48, respectively.

All Gravel Data

```
      *** Linear Model ***

Call: lm(formula = Agency.LCC ~ ADT, data = gravel, na.action = na.exclude)
Residuals:
    Min    1Q Median   3Q   Max
 -25341 -9105  -5121 8655 32045

Coefficients:
                 Value Std. Error    t value   Pr(>|t|)
(Intercept) 20878.8693  3413.5555     6.1165     0.0000
        ADT   136.9076    22.4559     6.0967     0.0000

Residual standard error: 15090 on 39 degrees of freedom
Multiple R-Squared: 0.488
F-statistic: 37.17 on 1 and 39 degrees of freedom, the p-value is 3.801e-007
```

=> With 95% confidence we can reject the null hypothesis (that the coefficients of the intercept and ADT are zero)and estimate the coefficients for the intercept and ADT to be 20878.86 and 136.91, respectively.

All Stabilized Gravel Data

```
      *** Linear Model ***

Call: lm(formula = Agency.LCC ~ ADT, data = stabilized.gravel, na.action =
      na.exclude)
Residuals:
    Min     1Q Median    3Q   Max
 -49599 -13781  -3800 22912 38501

Coefficients:
                 Value Std. Error    t value   Pr(>|t|)
(Intercept) 54386.8088 18591.7759     2.9253     0.0222
        ADT   167.6035    60.2548     2.7816     0.0272

Residual standard error: 31330 on 7 degrees of freedom
Multiple R-Squared: 0.525
F-statistic: 7.737 on 1 and 7 degrees of freedom, the p-value is 0.02724
```

Using Cook's Distance to check for outliers or data that is skewing the regression, 1 data point was determined to be an outlier and was removed from the linear regression. The results of the regression are shown below.

```
*** Linear Model ***

Call: lm(formula = Agency.LCC ~ ADT, data = stabilized.gravel, na.action =
      na.exclude)
Residuals:
    Min     1Q Median    3Q   Max
 -26708 -14962  -3920 17510 32819

Coefficients:
                 Value Std. Error    t value   Pr(>|t|)
(Intercept) 82843.5877 17377.6699     4.7672     0.0031
        ADT     8.7854    74.5795     0.1178     0.9101

Residual standard error: 22990 on 6 degrees of freedom
Multiple R-Squared: 0.002307
F-statistic: 0.01388 on 1 and 6 degrees of freedom, the p-value is 0.9101
```

=> Using 95% confidence we* CANNOT *reject the null hypothesis (that the coefficients of the intercept and ADT are zero).
Therefore, the best estimate of Life-cycle Cost is 82843.59 regardless of ADT.

APPENDIX E.
VEHICLE OPERATING COSTS (RUNNING COSTS)

Table E-1. Dollars running cost* at uniform speed on plus grades for 4-kip passenger cars in dollars per 1000 vehicle miles (Winfrey 1969).

Speed, mph	Plus Grade, Percent									Speed, mph
	Level	+1	+2	+3	+4	+5	+6	+7	+8	
5.0	59.36	61.27	63.29	65.46	67.68	70.33	72.53	75.23	78.49	5.0
7.5	49.86	51.81	53.90	56.09	58.35	60.57	63.24	66.02	69.28	7.5
10.0	44.93	46.89	49.01	51.24	53.53	55.59	58.46	61.31	64.57	10.0
12.5	41.82	43.81	46.00	48.23	50.52	52.77	55.55	58.44	61.70	12.5
15.0	39.73	41.74	43.94	46.20	48.50	51.00	53.58	56.49	59.78	15.0
17.5	38.21	40.23	42.47	44.72	47.05	49.47	52.16	55.13	58.41	17.5
20.0	37.09	39.12	41.37	43.66	45.99	48.49	51.12	54.14	57.41	20.0
22.5	36.23	38.31	40.55	42.88	45.21	47.71	50.37	53.42	56.69	22.5
25.0	35.63	37.72	39.96	42.27	44.62	47.12	49.83	52.93	56.20	25.0
27.5	35.19	37.28	39.53	41.86	44.22	46.74	49.48	52.60	55.90	27.5
30.0	34.91	37.02	39.27	41.62	43.99	46.52	49.27	52.46	55.79	30.0
32.5	34.79	36.88	39.12	41.45	43.87	46.43	49.21	52.39	55.78	32.5
35.0	34.76	36.84	39.07	41.43	43.83	46.39	49.23	52.47	55.89	35.0
37.5	34.84	36.89	39.11	41.46	43.91	46.51	49.34	52.62	56.12	37.5
40.0	35.03	37.08	39.28	41.62	44.09	46.73	49.60	52.87	56.43	40.0
42.5	35.27	37.28	39.54	41.86	44.33	46.96	49.89	53.22	56.81	42.5
45.0	35.63	37.63	39.88	42.17	44.64	47.31	50.28	53.65	57.32	45.0
47.5	36.13	38.15	40.39	42.67	45.16	47.80	50.82	54.25	57.98	47.5
50.0	36.53	38.53	40.74	43.03	45.53	48.22	51.26	54.73	58.53	50.0
52.5	37.07	39.07	41.34	43.55	46.07	48.79	51.86	55.38	59.16	52.5
55.0	37.71	39.72	41.89	44.19	46.70	49.47	52.57	56.14	60.11	55.0
57.5	38.50	40.48	42.65	44.97	47.49	50.29	53.46	57.05	61.12	57.5
60.0	39.42	41.43	43.57	45.87	48.42	51.29	54.47	58.14	62.33	60.0
62.5	40.49	42.49	44.63	46.92	49.49	52.40	55.72	59.41	62.33	62.5
65.0	41.71	43.75	45.87	48.19	50.77	53.74	57.13	59.41	62.33	65.0
67.5	43.12	45.17	47.30	49.66	52.24	55.33	57.13	59.41	62.33	67.5
70.0	44.76	46.79	48.94	51.32	53.97	55.33	57.13	59.41	62.33	70.0
72.5	46.63	48.68	50.85	53.28	53.97	55.33	57.13	59.41	62.33	72.5
75.0	48.79	50.86	53.07	55.59	53.97	55.33	57.13	59.41	62.33	75.0
77.5	51.34	53.36	55.62	55.59	53.97	55.33	57.13	59.41	62.33	77.5
80.0	54.35	56.36	58.69	55.59	53.97	55.33	57.13	59.41	62.33	80.0

* Cost includes fuel, tires, engine oil, maintenance and depreciation.

Table E-2. Dollars running cost* at uniform speed on plus grades for 5-kip commercial delivery truck in dollars per 1000 vehicle miles (Winfrey 1969).

Speed, mph	Plus Grade, Percent									Speed, mph
	Level	+1	+2	+3	+4	+5	+6	+7	+8	
5.0	64.35	66.19	68.12	70.25	72.67	75.53	78.85	82.79	87.37	5.0
7.5	54.57	56.31	58.39	60.54	62.99	65.84	69.27	73.24	77.86	7.5
10.0	49.49	51.35	53.42	55.70	58.26	61.14	64.49	68.43	73.10	10.0
12.5	46.31	48.20	50.28	52.59	55.17	58.13	61.52	65.59	70.23	12.5
15.0	44.15	46.09	48.21	50.57	53.18	56.16	59.56	63.60	68.40	15.0
17.5	42.55	44.55	46.70	49.07	51.74	54.73	58.22	62.26	67.15	17.5
20.0	41.39	43.43	45.60	48.01	50.72	53.74	57.26	61.39	66.30	20.0
22.5	40.58	42.60	44.82	47.29	50.02	53.10	56.64	60.79	65.79	22.5
25.0	39.95	42.03	44.27	46.77	49.52	52.69	56.28	60.48	65.54	25.0
27.5	39.55	41.63	43.95	46.52	49.31	52.49	56.14	60.40	65.53	27.5
30.0	39.32	41.45	43.82	46.41	49.27	52.48	56.87	60.54	65.75	30.0
32.5	39.24	41.43	43.82	46.47	49.39	52.67	56.44	60.84	66.18	32.5
35.0	39.29	41.54	43.99	46.69	49.67	53.03	58.67	61.37	66.83	35.0
37.5	39.48	41.78	44.30	47.06	50.09	53.51	57.43	62.06	67.67	37.5
40.0	39.83	42.22	44.79	47.62	50.72	54.23	58.24	62.99	68.86	40.0
42.5	40.28	42.74	45.41	48.31	51.51	55.07	59.20	64.12	70.23	42.5
45.0	40.88	43.44	46.21	49.20	52.48	56.19	60.42	65.56	72.07	45.0
47.5	41.74	44.40	47.29	50.33	53.75	57.55	62.01	67.42	74.47	47.5
50.0	42.49	45.26	48.22	51.45	54.99	58.97	63.66	69.50	77.33	50.0
52.5	43.48	46.37	49.49	52.82	56.50	60.68	65.63	72.09	77.33	52.5
55.0	44.72	47.74	50.98	54.48	58.34	62.74	65.63	72.09	77.33	55.0
57.5	46.23	49.41	52.83	56.53	60.56	65.20	65.63	72.09	77.33	57.5
60.0	48.11	51.46	55.09	59.01	60.56	65.20	65.63	72.09	77.33	60.0
62.5	50.37	53.97	57.87	59.01	60.56	65.20	65.63	72.09	77.33	62.5
65.0	53.10	56.94	61.58	59.01	60.56	65.20	65.63	72.09	77.33	65.0
67.5	56.16	60.35	61.58	59.01	60.56	65.20	65.63	72.09	77.33	67.5
70.0	59.70	64.28	61.58	59.01	60.56	65.20	65.63	72.09	77.33	70.0
72.5	59.70	64.28	61.58	59.01	60.56	65.20	65.63	72.09	77.33	72.5
75.0	59.70	64.28	61.58	59.01	60.56	65.20	65.63	72.09	77.33	75.0
77.5	59.70	64.28	61.58	59.01	60.56	65.20	65.63	72.09	77.33	77.5
80.0	59.70	64.28	61.58	59.01	60.56	65.20	65.63	72.09	77.33	80.0

* Cost includes fuel, tires, engine oil, maintenance and depreciation.

Table E-3. Dollars running cost* at uniform speed on plus grades for 12-kip single unit truck in dollars per 1000 vehicle miles (Winfrey 1969).

Speed, mph	Plus Grade, Percent									Speed, mph
	Level	+1	+2	+3	+4	+5	+6	+7	+8	
5.0	99.08	102.19	105.48	109.09	113.09	117.59	122.73	128.65	135.66	5.0
7.5	85.35	88.60	91.97	95.79	99.94	104.63	110.01	116.21	123.72	7.5
10.0	77.68	81.04	84.59	88.56	92.94	97.86	103.43	109.97	118.06	10.0
12.5	72.86	76.33	80.03	84.27	88.86	94.08	100.00	106.95	115.67	12.5
15.0	69.62	73.25	77.14	81.66	86.51	92.04	98.41	106.01	115.71	15.0
17.5	67.37	71.22	75.32	80.12	85.34	91.26	98.31	106.86	117.87	17.5
20.0	65.90	69.96	74.30	79.43	85.14	91.64	99.57	109.65	122.13	20.0
22.5	65.09	69.40	73.98	79.53	85.80	93.21	102.24	114.65	128.44	22.5
25.0	64.73	69.33	74.21	80.32	87.18	96.09	106.11	121.91	128.44	25.0
27.5	64.76	69.68	74.93	81.49	89.30	100.26	110.70	121.91	128.44	27.5
30.0	65.11	70.42	76.02	83.17	92.03	104.56	115.81	121.91	128.44	30.0
32.5	65.75	71.46	77.54	85.28	95.48	109.68	121.79	121.91	128.44	32.5
35.0	66.60	72.77	79.37	87.81	99.74	115.66	121.79	121.91	128.44	35.0
37.5	67.66	74.28	81.50	90.66	104.93	122.13	121.79	121.91	128.44	37.5
40.0	68.87	76.09	83.95	93.86	110.86	122.13	121.79	121.91	128.44	40.0
42.5	70.27	78.10	86.68	97.44	117.84	122.13	121.79	121.91	128.44	42.5
45.0	71.84	80.35	89.65	101.32	117.84	122.13	121.79	121.91	128.44	45.0
47.5	73.60	82.95	92.84	105.53	117.84	122.13	121.79	121.91	128.44	47.5
50.0	75.59	85.74	96.27	110.14	117.84	122.13	121.79	121.91	128.44	50.0
52.5	77.79	88.66	100.04	110.14	117.84	122.13	121.79	121.91	128.44	52.5
55.0	80.24	91.67	104.10	110.14	117.84	122.13	121.79	121.91	128.44	55.0
57.5	82.86	94.83	104.10	110.14	117.84	122.13	121.79	121.91	128.44	57.5
60.0	85.84	98.17	104.10	110.14	117.84	122.13	121.79	121.91	128.44	60.0
62.5	89.05	101.73	104.10	110.14	117.84	122.13	121.79	121.91	128.44	62.5
65.0	92.57	105.52	104.10	110.14	117.84	122.13	121.79	121.91	128.44	65.0
67.5	92.57	105.52	104.10	110.14	117.84	122.13	121.79	121.91	128.44	67.5
70.0	92.57	105.52	104.10	110.14	117.84	122.13	121.79	121.91	128.44	70.0
72.5	92.57	105.52	104.10	110.14	117.84	122.13	121.79	121.91	128.44	72.5
75.0	92.57	105.52	104.10	110.14	117.84	122.13	121.79	121.91	128.44	75.0
77.5	92.57	105.52	104.10	110.14	117.84	122.13	121.79	121.91	128.44	77.5
80.0	92.57	105.52	104.10	110.14	117.84	122.13	121.79	121.91	128.44	80.0

* Cost includes fuel, tires, engine oil, maintenance and depreciation.

Table E-4. Dollars running cost* at uniform speed on plus grades for 40-kip 2-S2 truck in dollars per 1000 vehicle miles (Winfrey 1969).

Speed, mph	Plus Grade, Percent									Speed, mph
	Level	+1	+2	+3	+4	+5	+6	+7	+8	
5.0	231.01	236.70	243.35	251.86	262.26	275.01	292.53	318.11	357.71	5.0
7.5	176.66	183.28	190.90	199.97	210.83	224.53	242.12	267.64	308.99	7.5
10.0	148.64	155.92	164.41	174.24	185.97	200.79	219.37	245.80	289.90	10.0
12.5	131.80	139.55	148.83	159.79	172.84	189.05	209.61	238.76	285.44	12.5
15.0	120.17	129.22	139.29	151.65	166.46	184.53	208.39	242.57	285.44	15.0
17.5	112.43	122.53	133.52	147.49	164.58	185.44	214.08	256.24	285.44	17.5
20.0	107.10	118.37	130.38	146.21	166.24	191.29	226.44	256.24	285.44	20.0
22.5	103.47	116.01	129.23	147.16	170.80	202.54	245.49	256.24	285.44	22.5
25.0	101.19	115.20	129.79	150.02	178.14	220.81	245.49	256.24	285.44	25.0
27.5	99.93	115.53	131.71	154.45	187.84	245.27	245.49	256.24	285.44	27.5
30.0	99.51	116.87	134.92	160.45	199.87	245.27	245.49	256.24	285.44	30.0
32.5	99.87	119.16	139.38	167.79	214.91	245.27	245.49	256.24	285.44	32.5
35.0	100.84	122.25	145.06	176.70	214.91	245.27	245.49	256.24	285.44	35.0
37.5	102.43	126.18	152.02	186.36	214.91	245.27	245.49	256.24	285.44	37.5
40.0	104.55	130.98	160.32	198.21	214.91	245.27	245.49	256.24	285.44	40.0
42.5	107.21	136.72	169.77	198.21	214.91	245.27	245.49	256.24	285.44	42.5
45.0	110.43	143.65	180.56	198.21	214.91	245.27	245.49	256.24	285.44	45.0
47.5	114.23	152.40	192.73	198.21	214.91	245.27	245.49	256.24	285.44	47.5
50.0	118.70	161.98	206.39	198.21	214.91	245.27	245.49	256.24	285.44	50.0
52.5	123.98	172.36	206.39	198.21	214.91	245.27	245.49	256.24	285.44	52.5
55.0	130.18	183.49	206.39	198.21	214.91	245.27	245.49	256.24	285.44	55.0
57.5	137.35	195.50	206.39	198.21	214.91	245.27	245.49	256.24	285.44	57.5
60.0	145.55	195.50	206.39	198.21	214.91	245.27	245.49	256.24	285.44	60.0
62.5	145.55	195.50	206.39	198.21	214.91	245.27	245.49	256.24	285.44	62.5
65.0	145.55	195.50	206.39	198.21	214.91	245.27	245.49	256.24	285.44	65.0
67.5	145.55	195.50	206.39	198.21	214.91	245.27	245.49	256.24	285.44	67.5
70.0	145.55	195.50	206.39	198.21	214.91	245.27	245.49	256.24	285.44	70.0
72.5	145.55	195.50	206.39	198.21	214.91	245.27	245.49	256.24	285.44	72.5
75.0	145.55	195.50	206.39	198.21	214.91	245.27	245.49	256.24	285.44	75.0
77.5	145.55	195.50	206.39	198.21	214.91	245.27	245.49	256.24	285.44	77.5
80.0	145.55	195.50	206.39	198.21	214.91	245.27	245.49	256.24	285.44	80.0

* Cost includes fuel, tires, engine oil, maintenance and depreciation.

Table E-5. Dollars running cost* at uniform speed on plus grades for 50-kip 2-S3 truck in dollars per 1000 vehicle miles (Winfrey 1969).

Speed, mph	Plus Grade, Percent									Speed, mph
	Level	+1	+2	+3	+4	+5	+6	+7	+8	
5.0	166.72	171.45	176.40	181.21	186.01	190.64	195.25	199.85	205.37	5.0
7.5	136.35	144.82	153.22	161.46	169.51	177.45	185.29	193.02	201.65	7.5
10.0	120.20	130.60	140.90	151.05	161.04	170.93	180.66	190.69	201.65	10.0
12.5	110.11	121.74	133.34	144.83	156.24	167.63	178.65	190.97	203.83	12.5
15.0	103.41	115.97	128.51	141.17	153.86	166.66	179.36	193.66	208.54	15.0
17.5	98.84	112.17	122.54	139.24	153.22	167.54	182.22	198.84	214.81	17.5
20.0	95.81	109.81	123.95	138.70	154.07	170.17	187.30	207.02	223.23	20.0
22.5	93.89	108.54	123.45	139.28	156.21	174.65	194.76	218.71	223.23	22.5
25.0	92.92	108.27	123.94	140.91	159.75	181.46	204.95	218.71	223.23	25.0
27.5	92.64	108.64	125.17	143.38	164.46	190.43	204.95	218.71	223.23	27.5
30.0	93.02	109.75	127.14	146.79	170.57	190.43	204.95	218.71	223.23	30.0
32.5	94.00	111.48	129.89	151.20	178.03	190.43	204.95	218.71	223.23	32.5
35.0	95.10	113.76	133.34	156.46	187.58	190.43	204.95	218.71	223.23	35.0
37.5	97.49	116.55	137.43	162.56	187.58	190.43	204.95	218.71	223.23	37.5
40.0	99.85	119.87	142.28	169.96	187.58	190.43	204.95	218.71	223.23	40.0
42.5	102.61	123.57	147.63	169.96	187.58	190.43	204.95	218.71	223.23	42.5
45.0	105.80	127.88	153.72	169.96	187.58	190.43	204.95	218.71	223.23	45.0
47.5	109.45	132.97	160.68	169.96	187.58	190.43	204.95	218.71	223.23	47.5
50.0	113.63	138.77	160.68	169.96	187.58	190.43	204.95	218.71	223.23	50.0
52.5	118.37	145.20	160.68	169.96	187.58	190.43	204.95	218.71	223.23	52.5
55.0	123.66	152.23	160.68	169.96	187.58	190.43	204.95	218.71	223.23	55.0
57.5	129.55	160.20	160.68	169.96	187.58	190.43	204.95	218.71	223.23	57.5
60.0	134.60	160.20	160.68	169.96	187.58	190.43	204.95	218.71	223.23	60.0
62.5	134.60	160.20	160.68	169.96	187.58	190.43	204.95	218.71	223.23	62.5
65.0	134.60	160.20	160.68	169.96	187.58	190.43	204.95	218.71	223.23	65.0
67.5	134.60	160.20	160.68	169.96	187.58	190.43	204.95	218.71	223.23	67.5
70.0	134.60	160.20	160.68	169.96	187.58	190.43	204.95	218.71	223.23	70.0
72.5	134.60	160.20	160.68	169.96	187.58	190.43	204.95	218.71	223.23	72.5
75.0	134.60	160.20	160.68	169.96	187.58	190.43	204.95	218.71	223.23	75.0
77.5	134.60	160.20	160.68	169.96	187.58	190.43	204.95	218.71	223.23	77.5
80.0	134.60	160.20	160.68	169.96	187.58	190.43	204.95	218.71	223.23	80.0

* Cost includes fuel, tires, engine oil, maintenance and depreciation.

APPENDIX F.
SUMMARY DATA FROM PARTICIPATING AGENCIES

Table F-1. Agency and user costs for HMA sections per mile for 20-year analysis.

Road	Surface	Agency Cost	Total User Costs	VOC Cost	Crash Cost	ADT
Bon Homme Co: CO RD 13	HMA	$ 57,500	$ 155,311	$ 112,707	$ 42,604	110
Codington Co: 23-6	HMA	$ 78,335	$ 832,800	$ 377,667	$ 455,133	300
Codington Co: 3-5	HMA	$ 83,016	$ 270,523	$ 235,659	$ 34,864	230
Codington Co: 4-7	HMA	$ 46,062	$ 104,389	$ 63,703	$ 40,686	70
Davison Co: 30-4-44	HMA	$ 59,625	$ 547,687	$ 345,816	$ 201,872	380
Day Co: #1	HMA	$ 66,084	$ 676,726	$ 512,303	$ 164,423	500
Douglas Co: 3-4	HMA	$ 63,482	$ 59,061	$ 56,878	$ 2,183	62.5
Douglas Co: 3-5	HMA	$ 53,341	$ 124,676	$ 124,676	$ -	137
Douglas Co: 500-2	HMA	$ 65,763	$ 322,256	$ 322,256	$ -	325
Douglas Co: 520-3	HMA	$ 43,767	$ 166,982	$ 166,982	$ -	200
Douglas Co: 560	HMA	$ 83,650	$ 1,117,239	$ 705,282	$ 411,957	775
Douglas Co: 7-3	HMA	$ 60,185	$ 289,938	$ 286,663	$ 3,275	315
Lincoln Co: #134	HMA	$ 83,963	$ 683,622	$ 682,531	$ 1,092	750
Lincoln Co: #148	HMA	$ 71,343	$ 457,932	$ 455,021	$ 2,911	500
McCook Co: 16A	HMA	$ 35,194	$ 232,999	$ 184,429	$ 48,570	180
McCook Co: 25	HMA	$ 72,121	$ 190,457	$ 174,183	$ 16,275	170
McCook Co: 25A	HMA	$ 45,857	$ 103,271	$ 81,968	$ 21,302	80
McCook Co: 4A	HMA	$ 55,776	$ 198,827	$ 184,429	$ 14,398	180
McCook Co: 9A	HMA	$ 63,581	$ 543,437	$ 502,057	$ 41,380	490
Miner Co: #7	HMA	$ 96,680	$ 676,500	$ 391,318	$ 285,182	430
Miner Co: Road #17	HMA	$ 74,788	$ 206,813	$ 200,209	$ 6,604	220
Minnehaha Co: #105N	HMA	$ 94,496	$ 738,494	$ 637,029	$ 101,466	700
Minnehaha Co: #119	HMA	$ 119,489	$ 1,588,852	$ 1,365,061	$ 223,791	1500
Minnehaha Co: #137	HMA	$ 125,594	$ 2,320,710	$ 2,275,102	$ 45,608	2500
Pennington Co: Sheridan Lake Rd	HMA	$ 131,440	$ 713,916	$ 703,031	$ 10,885	700
Perkins Co: C2	HMA	$ 53,247	$ 70,966	$ 66,599	$ 4,367	65
Perkins Co: C2b	HMA	$ 77,068	$ 70,966	$ 66,599	$ 4,367	65
Perkins Co: C2S	HMA	$ 74,554	$ 162,559	$ 128,076	$ 34,483	125
Perkins Co: C9	HMA	$ 79,570	$ 101,704	$ 97,338	$ 4,367	95
Perkins Co: C9A	HMA	$ 80,531	$ 89,627	$ 76,845	$ 12,781	75
Potter Co: #155	HMA	$ 49,463	$ 93,777	$ 81,968	$ 11,809	80
Sanborn Co: #9-0	HMA	$ 79,393	$ 291,216	$ 263,912	$ 27,304	290
Turner Co: #17	HMA	$ 89,180	$ 1,377,554	$ 1,350,430	$ 27,124	1318
Turner Co: #41	HMA	$ 50,984	$ 715,460	$ 295,763	$ 419,697	325
Walworth Co: Township Indian Creek	HMA	$ 41,135	$ 204,921	$ 204,921	$ -	200

Table F-2. Agency and user costs for blotter sections per mile for 20-year analysis.

Road	Surface	Agency Cost	Total User Costs	VOC Cost	Crash Cost	ADT
Bon Homme Co: CO RD 15	Blotter	$ 36,733	$ 199,838	$ 198,965	$ 873	187.5
Codington Co: 16	Blotter	$ 45,505	$ 305,476	$ 198,965	$ 106,511	187.5
Davison Co: 31-41-17	Blotter	$ 36,745	$ 356,996	$ 198,965	$ 158,032	187.5
Day Co: #12	Blotter	$ 31,201	$ 151,638	$ 137,481	$ 14,157	115
Day Co: #4	Blotter	$ 41,463	$ 574,172	$ 537,969	$ 36,203	450
Douglas Co: 23-2	Blotter	$ 50,470	$ 483,338	$ 477,515	$ 5,822	450
Douglas Co: 560-2	Blotter	$ 32,995	$ 249,369	$ 249,369	$ -	235
Douglas Co: 580-2	Blotter	$ 32,042	$ 585,511	$ 196,312	$ 389,199	185
Douglas Co: 580-6	Blotter	$ 25,944	$ 91,725	$ 66,322	$ 25,403	62.5
Edmunds Co: #1 South	Blotter	$ 61,466	$ 414,791	$ 221,165	$ 193,626	185
Edmunds Co: #11	Blotter	$ 69,867	$ 313,051	$ 291,815	$ 21,236	275
Edmunds Co: #15 North	Blotter	$ 43,706	$ 388,023	$ 153,866	$ 234,156	145
Edmunds Co: #24	Blotter	$ 36,924	$ 155,269	$ 143,255	$ 12,014	135
Edmunds Co: #7	Blotter	$ 77,010	$ 194,225	$ 185,300	$ 8,924	155
Hand Co: County Rd 33-0	Blotter	$ 45,992	$ 165,708	$ 148,560	$ 17,148	140
Kinsbury Co: CR #1	Blotter	$ 72,233	$ 668,652	$ 530,573	$ 138,080	500
Kinsbury Co: CR #9	Blotter	$ 70,484	$ 440,574	$ 424,458	$ 16,115	400
McCook Co: 8	Blotter	$ 25,041	$ 252,832	$ 224,154	$ 28,678	187.5
McPherson Co: #17	Blotter	$ 32,263	$ 105,776	$ 100,695	$ 5,081	80
Miner Co: #2	Blotter	$ 36,120	$ 149,574	$ 137,949	$ 11,625	130
Miner Co: #8	Blotter	$ 59,777	$ 145,158	$ 131,503	$ 13,655	110
Pennington Co: Old Hill City Rd	Blotter	$ 83,179	$ 903,111	$ 717,521	$ 185,590	567
Potter Co: #162	Blotter	$ 33,416	$ 93,109	$ 74,718	$ 18,391	62.5
Turner Co: #32	Blotter	$ 69,741	$ 358,527	$ 344,872	$ 13,655	325
Walworth Co: #245	Blotter	$ 49,016	$ 1,503,923	$ 366,095	$ 1,137,828	345

Table F-3. Agency and user costs for gravel sections per mile for 20-year analysis.

Road	Surface	Agency Cost	Total User Costs	VOC Cost	Crash Cost	ADT
Bon Homme Co: Avon Twp	Gravel	$ 22,698	$ 96,126	$ 85,210	$ 10,916	62.5
Codington Co: 18	Gravel	$ 20,572	$ 85,937	$ 85,210	$ 728	62.5
Codington Co: 20-1	Gravel	$ 23,879	$ 256,721	$ 255,629	$ 1,092	187.5
Custer Co: E. French Creek Rd.	Gravel	$ 43,961	$ 109,585	$ 109,068	$ 517	80
Custer Co: Ghost Canyon CS360	Gravel	$ 67,939	$ 829,525	$ 819,406	$ 10,119	500
Custer Co: Limestone Rd CS 284	Gravel	$ 100,508	$ 605,423	$ 573,584	$ 31,839	350
Custer Co: Lower French Creek CS341	Gravel	$ 49,890	$ 496,471	$ 470,802	$ 25,669	325
Custer Co: Medicine Mtn CS297	Gravel	$ 61,854	$ 326,398	$ 258,687	$ 67,712	170
Custer Co: Pass Creek CS273	Gravel	$ 41,447	$ 282,132	$ 273,341	$ 8,791	205
Custer Co: Pleasant Valley FAS 715	Gravel	$ 46,227	$ 285,458	$ 274,084	$ 11,374	200
Custer Co: Spring Creek Cutoff FAS152	Gravel	$ 26,991	$ 56,142	$ 54,962	$ 1,180	46
Custer Co: Upper French Creek CS286	Gravel	$ 39,812	$ 377,233	$ 301,199	$ 76,034	187.5
Edmunds Co: #15 South	Gravel	$ 23,442	$ 203,298	$ 197,686	$ 5,612	145
Edmunds Co: #16	Gravel	$ 32,888	$ 87,393	$ 85,210	$ 2,183	62.5
Edmunds Co: #26	Gravel	$ 45,338	$ 82,893	$ 81,801	$ 1,092	60
Edmunds Co: #3	Gravel	$ 19,194	$ 47,365	$ 46,117	$ 1,248	30
Edmunds Co: #4A	Gravel	$ 16,803	$ 85,210	$ 85,210	$ -	62.5
Edmunds Co: #5	Gravel	$ 19,180	$ 38,704	$ 38,431	$ 273	25
Edmunds Co: #6	Gravel	$ 16,566	$ 55,550	$ 53,804	$ 1,747	35
Edmunds Co: #8	Gravel	$ 21,208	$ 291,479	$ 288,234	$ 3,245	187.5
Gregory Co: CR-42	Gravel	$ 71,406	$ 190,007	$ 184,053	$ 5,954	135
Hand Co: Country Rd 15-G	Gravel	$ 32,904	$ 109,899	$ 85,210	$ 24,689	62.5
McCook Co: 23A	Gravel	$ 19,879	$ 97,533	$ 96,078	$ 1,456	62.5
Miner Co: #25	Gravel	$ 29,230	$ 324,247	$ 85,210	$ 239,037	62.5
Miner Co: #9	Gravel	$ 26,956	$ 119,526	$ 85,210	$ 34,316	62.5
Pennington Co: East Slate Rd	Gravel	$ 44,639	$ 342,785	$ 338,418	$ 4,367	70
Pennington Co: Edelweiss Mt Rd	Gravel	$ 96,010	$ 528,707	$ 460,662	$ 68,046	318
Pennington Co: Horse Creek Rd	Gravel	$ 45,916	$ 86,917	$ 86,917	$ -	60
Pennington Co: Mystic Rd	Gravel	$ 46,714	$ 320,326	$ 290,318	$ 30,008	169
Perkins Co: C1	Gravel	$ 21,065	$ 138,352	$ 138,352	$ -	90
Perkins Co: C10	Gravel	$ 22,441	$ 33,671	$ 15,372	$ 18,299	10

Table F-3. Agency and user costs for gravel sections per mile for 20-year analysis (continued).

Road	Surface	Agency Cost	Total User Costs	VOC Cost	Crash Cost	ADT
Perkins Co: C13	Gravel	$ 14,213	$ 32,928	$ 30,745	$ 2,183	20
Perkins Co: C17	Gravel	$ 25,354	$ 38,431	$ 38,431	$ -	25
Perkins Co: C2	Gravel	$ 16,767	$ 78,172	$ 76,862	$ 1,310	50
Perkins Co: C6	Gravel	$ 18,742	$ 76,862	$ 76,862	$ -	50
Perkins Co: T24	Gravel	$ 14,138	$ 18,447	$ 18,447	$ -	12
Potter Co: All FSA	Gravel	$ 24,036	$ 107,113	$ 96,078	$ 11,035	62.5
Sanborn Co: #21	Gravel	$ 48,719	$ 64,626	$ 61,351	$ 3,275	45
Turner Co: #34	Gravel	$ 19,838	$ 47,717	$ 47,717	$ -	35
Walworth Co: #119	Gravel	$ 38,091	$ 85,210	$ 85,210	$ -	62.5
Walworth Co: Township Schlouer Rd	Gravel	$ 56,034	$ 100,444	$ 96,078	$ 4,367	62.5

Table F-4. Agency and user costs for stabilized gravel sections per mile for 20-year analysis.

Road	Surface	Agency Cost	Total User Costs	VOC Cost	Crash Cost	ADT
Custer Co: 7-11 FAS 101	Stabilized Gravel	$ 83,270	$ 340,368	$ 288,470	$ 51,898	195
Custer Co: America Center CS345	Stabilized Gravel	$ 118,517	$ 503,665	$ 393,318	$ 110,347	325
Day Co: #1C	Stabilized Gravel	$ 72,031	$ 307,001	$ 256,194	$ 50,807	187.5
Lawrence Co: 010A	Stabilized Gravel	$ 79,145	$ 509,658	$ 412,237	$ 97,421	325
Lawrence Co: 195	Stabilized Gravel	$ 197,328	$ 972,641	$ 888,321	$ 84,320	650
Lawrence Co: 23B	Stabilized Gravel	$ 63,449	$ 469,510	$ 443,947	$ 25,563	350
McCook Co: 11	Stabilized Gravel	$ 56,684	$ 77,221	$ 75,766	$ 1,456	62.5
Turner Co: #13	Stabilized Gravel	$ 103,363	$ 86,853	$ 85,398	$ 1,456	62.5
Turner Co: #37	Stabilized Gravel	$ 100,763	$ 193,928	$ 169,715	$ 24,213	140

Table F-5. Characteristics of HMA sections.

Road	Length (miles)	Terrain	Subgrade	Truck Traffic	Distance to Aggregate Source (miles)	Speed Limit	Housing Density
Bon Homme Co: CO RD 13	6	Rolling	Good	Low	60	55	Low
Codington Co: 23-6	5.3	Flat	Good	Low	11	55	Low
Codington Co: 3-5	6	Rolling	Good	Low	7	55	Low
Codington Co: 4-7	2	Flat	Good	Low	10	55	Low
Davison Co: 30-4-44	14	Flat	Poor	High	19	55	Low
Day Co: #1	26	Rolling	Good	Low	5	55	Low
Douglas Co: 3-4	2	Flat	Good	High	10	55	Low
Douglas Co: 3-5	1.75	Flat	Poor	Low	10	55	Low
Douglas Co: 500-2	1	Rolling	Poor	High	6	20	High
Douglas Co: 520-3	1	Flat	Good	High	15	30	Low
Douglas Co: 560	6	Flat	Good	High	40	55	Low
Douglas Co: 7-3	4	Flat	Poor	High	20	55	Low
Lincoln Co: #134	4	Flat	--	--	--	55	--
Lincoln Co: #148	6	Flat	--	--	--	55	--
McCook Co: 16A	1	Rolling	Poor	High	14	55	Low
McCook Co: 25	5	Rolling	Good	Low	2	55	Low
McCook Co: 25A	3	Rolling	Good	High	11	55	Low
McCook Co: 4A	11	Rolling	Good	Low	10	55	Low
McCook Co: 9A	4	Rolling	Good	Low	16	55	High
Miner Co: #7	11	Flat	Good	High	20	55	Low
Miner Co: Road #17	11	Flat	Good	Low	35	55	Low
Minnehaha Co: #105N	8	Flat	--	--	--	55	--
Minnehaha Co: #119	6	Flat	--	--	--	55	--
Minnehaha Co: #137	17	Flat	--	--	--	55	--
Pennington Co: Sheridan Lake Rd	5.47	Mountainous	Good	Low	--	50	High
Perkins Co: C2	1	Rolling	Good	Low	1	55	Low
Perkins Co: C2b	1	Rolling	Good	High	2	55	Low
Perkins Co: C2S	1.6	Rolling	Good	High	12	55	Low
Perkins Co: C9	7.5	Rolling	Good	High	9	55	Low
Perkins Co: C9A	10	Rolling	Good	High	9	55	Low
Potter Co: #155	16	Rolling	Good	High	20	55	Low
Sanborn Co: #9-0	14	Flat	Good	Low	4	55	Low
Turner Co: #17	3	Rolling	Good	High	7	55	High
Turner Co: #41	6	Flat	Good	Low	18	55	Low
Walworth Co: Township Indian Creek	1	Rolling	Good	Low	6	55	Low

Table F-6. Characteristics of blotter sections.

Road	Length (miles)	Terrain	Subgrade	Truck Traffic	Distance to Aggregate Source (miles)	Speed Limit	Housing Density
Bon Homme Co: CO RD 15	5	Flat	Poor	Low	60	55	Low
Codington Co: 16	3	Flat	Good	Low	12	55	Low
Davison Co: 31-41-17	16	Flat	Poor	High	--	55	Low
Day Co: #12	12	Rolling	Poor	Low	20	55	Low
Day Co: #4	20	Rolling	Good	High	20	55	Low
Douglas Co: 23-2	3	Flat	Poor	High	50	55	Low
Douglas Co: 560-2	3	Flat	Good	Low	25	55	Low
Douglas Co: 580-2	6	Flat	Good	Low	20	55	Low
Douglas Co: 580-6	2	Flat	Poor	Low	20	55	Low
Edmunds Co: #1 South	15	Rolling	Good	High	1	55	Low
Edmunds Co: #11	8	Flat	Good	High	38	55	Low
Edmunds Co: #15 North	10.5	Flat	Good	High	48	55	Low
Edmunds Co: #24	16	Flat	Poor	High	42	55	Low
Edmunds Co: #7	14.5	Rolling	Poor	High	18	55	Low
Hand Co: County Rd 33-0	4.975	Flat	Poor	High	19	55	Low
Kinsbury Co: CR #1	21	Flat	--	--	--	--	--
Kinsbury Co: CR #9	9.5	Flat	--	High	--	--	--
McCook Co: 8	4	Rolling	Good	High	5	55	Low
McPherson Co: #17	10	Rolling	--	--	--	55	--
Miner Co: #2	7	Flat	Good	Low	41	55	Low
Miner Co: #8	5	Rolling	Poor	Low	36	55	Low
Pennington Co: Old Hill City Rd	4.1	Rolling	Good	Low	--	35	--
Potter Co: #162	3	Rolling	Good	High	2	55	Low
Turner Co: #32	5	Flat	Good	High	9	55	Low
Walworth Co: #245	2	Rolling	Poor	Low	3	55	Low

Table F-7. Characteristics of gravel sections.

Road	Length (miles)	Terrain	Subgrade	Truck Traffic	Distance to Aggregate Source (miles)	Speed Limit	Housing Density
Bon Homme Co: Avon Twp	0.8	Flat	Poor	Low	10	55	Low
Codington Co: 18	6	Flat	Poor	High	10	55	Low
Codington Co: 20-1	4	Flat	Poor	High	11	55	Low
Custer Co: E. French Creek Rd.	16.9	Flat	Good	Low	10	55	Low
Custer Co: Ghost Canyon CS360	7.61	Mountainous	Good	High	15	45	High
Custer Co: Limestone Rd CS 284	8.44	Mountainous	Poor	High	5	45	Low
Custer Co: Lower French Creek CS341	5.93	Mountainous	Good	Low	5	25	High
Custer Co: Medicine Mtn CS297	4.75	Mountainous	Good	High	5	35	Low
Custer Co: Pass Creek CS273	11.74	Rolling	Good	Low	1	45	High
Custer Co: Pleasant Valley FAS 715	28.72	Rolling	Good	Low	10	45	High
Custer Co: Spring Creek Cutoff FAS152	7.4	Flat	Good	Low	3	45	Low
Custer Co: Upper French Creek CS286	2.96	Mountainous	Poor	Low	4	35	High
Edmunds Co: #15 South	14.5	Flat	Good	High	46	55	Low
Edmunds Co: #16	8	Flat	Good	High	43	55	Low
Edmunds Co: #26	16	Flat	Poor	Low	52	55	Low
Edmunds Co: #3	14	Rolling	Good	High	8	55	Low
Edmunds Co: #4A	4	Flat	Poor	Low	12	55	Low
Edmunds Co: #5	16	Rolling	Good	High	15	55	Low
Edmunds Co: #6	5	Rolling	Poor	Low	15	55	Low
Edmunds Co: #8	17	Rolling	Poor	High	20	55	Low
Gregory Co: CR-42	10	Flat	Good	High	15	55	Low
Hand Co: Country Rd 15-G	5	Flat	Good	Low	--	55	Low
McCook Co: 23A	3	Rolling	Good	High	18	55	Low
Miner Co: #25	10	Flat	Good	High	3	55	Low
Miner Co: #9	11	Flat	Good	Low	10	55	Low
Pennington Co: East Slate Rd	4	Mountainous	Good	High	10	50	Low
Pennington Co: Edelweiss Mt Rd	3.5	Mountainous	Good	--	20	25	Low
Pennington Co: Horse Creek Rd	0.32	Mountainous	Good	Low	22	25	Low
Pennington Co: Mystic Rd	7.5	Mountainous	Poor	Low	18	50	Low
Perkins Co: C1	4	Rolling	--	High	1	55	Low

Table F-7. Characteristics of gravel sections (continued).

Road	Length (miles)	Terrain	Subgrade	Truck Traffic	Distance to Aggregate Source (miles)	Speed Limit	Housing Density
Perkins Co: C10	6	Rolling	--	High	9	55	Low
Perkins Co: C13	8	Rolling	--	High	9	55	Low
Perkins Co: C17	3	Rolling	--	High	16	55	Low
Perkins Co: C2	4.3	Rolling	--	High	1	55	Low
Perkins Co: C6	2	Rolling	--	High	1	55	Low
Perkins Co: T24	5	Rolling	--	High	14	55	Low
Potter Co: All FSA	10	Rolling	Good	High	17	55	Low
Sanborn Co: #21	12	Flat	Good	Low	6	55	Low
Turner Co: #34	4	Flat	Good	Low	18	55	Low
Walworth Co: #119	1.5	Flat	Good	Low	7	55	Low
Walworth Co: Township Schlouer Rd	1	Rolling	Good	Low	1	55	Low

Table F-8. Characteristics of stabilized gravel sections.

Road	Length (miles)	Terrain	Subgrade	Truck	Distance to Aggregate Source	Speed Limit	Housing Density
Custer Co: 7-11 FAS 101	11.13	Rolling	Good	High	5	45	Low
Custer Co: America Center CS345	3.86	Mountainous	Good	High	5	45	High
Day Co: #1C	1	Rolling	Good	Low	5	55	Low
Lawrence Co: 010A	4.25	Rolling	Good	Low	11	40	Low
Lawrence Co: 195	8.577	Mountainous	Good	Low	6	30	High
Lawrence Co: 23B	4.969	Rolling	Poor	Low	12	40	Low
McCook Co: 11	3	Flat	Good	High	2	55	Low
Turner Co: #13	3	Rolling	Good	Low	27	55	Low
Turner Co: #37	3	Flat	Good	Low	3.5	55	Low

Table F-9. Crash occurrences per mile over 10-year period for HMA sections.

Road	Fatal	Injury	Property Damage
Bon Homme Co: CO RD 13	0.00	0.67	2.00
Codington Co: 23-6	0.19	0.38	1.89
Codington Co: 3-5	0.00	0.50	2.17
Codington Co: 4-7	0.00	0.50	3.50
Davison Co: 30-4-44	0.07	0.57	2.50
Day Co: #1	0.04	1.38	1.58
Douglas Co: 3-4	0.00	0.00	0.50
Douglas Co: 3-5	0.00	0.00	0.00
Douglas Co: 500-2	0.00	0.00	0.00
Douglas Co: 520-3	0.00	0.00	0.00
Douglas Co: 560	0.17	0.50	2.00
Douglas Co: 7-3	0.00	0.00	0.75
Lincoln Co: #134	0.00	0.75	0.30
Lincoln Co: #148	0.00	0.00	0.70
McCook Co: 16A	0.09	0.91	0.55
McCook Co: 25	0.00	0.20	1.40
McCook Co: 25A	0.00	0.33	1.00
McCook Co: 4A	0.00	0.18	1.18
McCook Co: 9A	0.00	0.75	0.75
Miner Co: #7	0.09	1.18	4.36
Miner Co: Road #17	0.00	0.09	0.45
Minnehaha Co: #105N	0.00	1.75	2.88
Minnehaha Co: #119	0.00	3.70	8.20
Minnehaha Co: #137	0.00	0.70	2.30
Pennington Co: Sheridan Lake Rd	0.00	0.18	3.70
Perkins Co: C2	0.00	0.00	1.00
Perkins Co: C2b	0.00	0.00	1.00
Perkins Co: C2S	0.00	0.60	0.60
Perkins Co: C9	0.00	0.00	1.00
Perkins Co: C9A	0.00	0.20	0.60
Potter Co: #155	0.00	0.13	1.25
Sanborn Co: #9-0	0.00	0.29	2.93
Turner Co: #17	0.00	0.33	1.67
Turner Co: #41	0.17	0.67	1.83
Walworth Co: Township Indian Creek	0.00	0.00	0.00

Table F-10. Crash occurrences per mile over 10-year period for blotter sections.

Road	Fatal	Injury	Property Damage
Bon Homme Co: CO RD 15	0.00	0.00	0.02
Codington Co: 16	0.00	0.17	0.50
Davison Co: 31-41-17	0.01	0.02	0.14
Day Co: #12	0.00	0.03	0.03
Day Co: #4	0.00	0.06	0.11
Douglas Co: 23-2	0.00	0.00	0.13
Douglas Co: 560-2	0.00	0.00	0.00
Douglas Co: 580-2	0.02	0.02	0.07
Douglas Co: 580-6	0.00	0.05	0.00
Edmunds Co: #1 South	0.01	0.07	0.12
Edmunds Co: #11	0.00	0.04	0.05
Edmunds Co: #15 North	0.01	0.03	0.09
Edmunds Co: #24	0.00	0.01	0.12
Edmunds Co: #7	0.00	0.01	0.12
Hand Co: Country Rd 33-0	0.00	0.02	0.16
Kinsbury Co: CR #1	0.01	0.03	0.23
Kinsbury Co: CR #9	0.00	0.03	0.02
McCook Co: 8	0.00	0.05	0.08
McPherson Co: #17	0.00	0.01	0.00
Miner Co: #2	0.02	0.02	0.07
Miner Co: #8	0.00	0.02	0.08
Pennington Co: Old Hill City Rd	0.00	0.32	0.56
Potter Co: #162	0.00	0.03	0.03
Turner Co: #32	0.00	0.02	0.08
Walworth Co: #245	0.05	0.00	0.10

Table F-11. Crash occurrences per mile over 10-year period for gravel sections.

Road	Fatal	Injury	Property Damage
Bon Homme Co: Avon Twp	0.00	0.00	0.25
Codington Co: 18	0.00	0.00	0.02
Codington Co: 20-1	0.00	0.00	0.03
Custer Co: E. French Creek Rd.	0.00	0.00	0.01
Custer Co: Ghost Canyon CS360	0.00	0.01	0.08
Custer Co: Limestone Rd CS 284	0.00	0.05	0.18
Custer Co: Lower French Creek CS341	0.00	0.02	0.10
Custer Co: Medicine Mtn CS297	0.00	0.13	0.08
Custer Co: Pass Creek CS273	0.00	0.01	0.10
Custer Co: Pleasant Valley FAS 715	0.00	0.02	0.02
Custer Co: Spring Creek Cutoff FAS152	0.00	0.00	0.03

Table F-11. Crash occurrences per mile over 10-year period for gravel sections (continued).

Road	Fatal	Injury	Property Damage
Custer Co: Upper French Creek CS286	0.00	0.14	0.17
Edmunds Co: #15 South	0.00	0.01	0.48
Edmunds Co: #16	0.00	0.00	0.05
Edmunds Co: #26	0.00	0.00	0.03
Edmunds Co: #3	0.00	0.00	0.03
Edmunds Co: #4A	0.00	0.00	0.00
Edmunds Co: #5	0.00	0.00	0.01
Edmunds Co: #6	0.00	0.00	0.04
Edmunds Co: #8	0.00	0.01	0.01
Gregory Co: CR-42	0.00	0.10	0.02
Hand Co: Country Rd 15-G	0.00	0.04	0.10
McCook Co: 23A	0.00	0.00	0.03
Miner Co: #25	0.01	0.02	0.05
Miner Co: #9	0.00	0.06	0.05
Pennington Co: East Slate Rd	0.00	0.00	0.10
Pennington Co: Edelweiss Mt Rd	0.00	0.11	0.23
Pennington Co: Horse Creek Rd	0.00	0.00	0.00
Pennington Co: Mystic Rd	0.00	0.08	0.11
Perkins Co: C1	0.00	0.00	0.00
Perkins Co: C10	0.00	0.03	0.07
Perkins Co: C13	0.00	0.00	0.05
Perkins Co: C17	0.00	0.00	0.00
Perkins Co: C2	0.00	0.00	0.03
Perkins Co: C6	0.00	0.00	0.00
Perkins Co: T24	0.00	0.00	0.00
Potter Co: All FSA	0.00	0.02	0.02
Sanborn Co: #21	0.00	0.00	0.08
Turner Co: #34	0.00	0.00	0.00
Walworth Co: #119	0.00	0.00	0.00
Walworth Co: Township Schlouer Rd	0.00	0.00	0.10

Table F-12. Crash occurrences per mile over 10-year period for stabilized gravel sections.

Road	Fatal	Injury	Property Damage
Custer Co: 7-11 FAS 101	0.00	0.04	0.09
Custer Co: America Center CS345	0.00	0.21	0.21
Day Co: #1C	0.00	0.10	0.00
Lawrence Co: 010A	0.00	0.20	0.20
Lawrence Co: 195	0.00	0.10	0.30
Lawrence Co: 23B	0.00	0.04	0.12
McCook Co: 11	0.00	0.00	0.03
Turner Co: #13	0.00	0.00	0.03
Turner Co: #37	0.00	0.03	0.17

APPENDIX G.
TECHNICAL BRIEF

LOCAL ROAD SURFACING CRITERIA
(SD2002-10)
TECHNICAL BRIEF

Introduction

On a daily basis, local road agencies in South Dakota face the challenge of how to cost-effectively maintain low-volume roads. Specifically, decision makers are faced with the challenge of determining when it is most economical to maintain, upgrade, or downgrade a road's existing surface. For example, an agency might need to determine when it is most cost-effective to convert a gravel road to a blotter road.

In order to assist decision makers with these types of questions, the South Dakota Department of Transportation (SDDOT) initiated a research study in 2002 regarding surfacing criteria for low-volume roads. The objective of this research study is to create a process that allows the user to compare the costs associated with different types of roads to provide assistance in deciding which surface type is most economical under a specific set of circumstances. In addition to incorporating the economical factors, the process must also allow the user to consider other non-economic factors that are more subjective and difficult to quantify, such as political factors, growth rates, housing concentration, mail routes, and industry/truck traffic. The process that was developed can be performed manually, as outlined in this *Technical Brief*, or through the use of a computerized tool developed under this project and available through the South Dakota Local Technical Assistance Program (SDLTAP).

The *Technical Brief* was developed to provide a step-by-step procedure for making road surface type decisions between different surface materials (hot-mix asphalt [HMA], blotter, gravel, and stabilized gravel) on low volume roadways. The approach outlined in this document is flexible enough to allow users to consider only those costs actually incurred by the agency for maintaining their roads, to include non-agency cost factors such as vehicle operating costs or crash potential, or to include non-economic factors. Whatever considerations are included in the analysis, the methodology presented in this *Technical Brief* provides a practical tool to assist agencies with decisions about the most cost-effective road surface type to be used in various situations.

Methodology

The decision of the most cost-effective surface type to be used on a road can be heavily influenced by the initial cost of constructing the road, the maintenance costs expected over its life, and the impact the road surface might have on its users. These factors have all been incorporated into the methodology outlined in this *Technical Brief.* The approach is based on an analysis of both costs and non-economic factors that might influence an agency's selection of the appropriate road surface to be used. In the process developed under this study, there are several different types of costs considered. The term *agency cost* is used to define the funds expended by the local agency to build and maintain the given roadway over its life. In addition to agency costs, the analysis may optionally consider *user costs*. User costs typically include the vehicle operating, crash, and delay costs incurred by the users of a roadway. During an analysis, all, some, or none of the user costs may be included as selected by the agency. For this analysis, only the vehicle operating and crash components of the user costs are included as options in the cost analysis.

In order to calibrate the methodology to the local agencies in South Dakota, all counties in the state were asked to participate in providing data related to specific road sections in their county. An attempt was made to collect data for all road surface types having a full range of average daily traffic (ADT) and truck percentage levels for all terrain types. Using the data provided by participating counties, the project models were customized to reflect typical costs in South Dakota. These models, which were developed based upon an analysis of the costs incurred over the anticipated life of each road section, allow the user to determine the most cost-effective surface for a given set of roadway conditions. The method for determining the optimal surface type using a manual approach is described in the next section of this *Technical Brief*. The consideration of the time value of money is incorporated into the automated tool available through the SDLTAP but was omitted from the *Technical Brief* to keep the manual process from becoming too complex. The salvage value of treatments at the end of the analysis period is also ignored in this manual approach but may be included in the analysis conducted using the automated tool.

Procedure

This section provides the details necessary for an agency to determine the most appropriate surface type for a given pavement section based upon the average conditions observed in South Dakota. To apply the methodology developed for this study, the following steps should be followed. An example analysis (displayed in italics) is provided along with the step-by-step procedure.

Step 1. Identify the Road Section

The first step in determining the appropriate surface type for a given roadway section is to identify the road section of interest. You must decide what portion of the roadway you want to consider in your analysis. Further, for the chosen roadway section, you must also identify the corresponding average daily traffic (ADT) value associated with the entire length of the roadway section that you are considering. The ADT value may be based upon traffic counts that have been conducted on the section or estimated based upon your knowledge of the road section. Details about the section (such as road name, location, and ADT) should be added to lines 1 through 3 on the summary table (table 12) that is included on page 14 of this *Technical Brief*.

Example: County A has a 5-mile section of County Road 1 that had been gravel surfaced since it was initially constructed. Since its initial construction, the ADT has increased on the roadway section to 350 vehicles per day (based upon a recently conducted traffic count). County A is considering surfacing the pavement section. Currently, they are receiving political pressure to pave the road, but they are unsure if they should construct a blotter or HMA road. The section details were added to lines 1 through 3 on the example summary table (table 13) on page 14 of this Technical Brief.

Step 2. Determine the Agency Costs

The next step in selecting the surface type for a given roadway section is to calculate the agency component of the total costs expected to be incurred over the life of the roadway. Tables 1 through 4 allow you to determine the agency costs associated with the pavement section if it is surfaced with HMA, blotter, gravel, or stabilized gravel, respectively. Further information on filling out these tables is provided.

Table 1. Agency costs for HMA surfaced roadway section.

Column 1	Column 2	Column 3	Column 4	Column 5
Treatment	**Number of Applications Per Year (times/yr)**	**How Often the Treatment is Applied (years between applications)**	**Costs Per Application (cost/mile)**	**Costs Per Mile Per Year** **column 2* column 4** / **column 3**
Line 1: Crack Sealing				
Line 2: Seal Coat				
Line 3: Overlay				
Line 4: Striping and Marking				
Line 5: Patching				
Line 6: Other ___________				
Line 7: Maintenance Costs Per Mile Per Year (Sum Lines 1 through 6)				
Line 8: Analysis Period (years)				20
Line 9: Maintenance Costs Per Mile for the Analysis Period (Line 7 * Line 8)				
Line 10: Initial Construction/ Last Major Rehabilitation Costs (costs/mile)				
Line 11: Total 20-year Costs Per Mile (Line 9 + Line 10)				

Table 2. Agency costs for blotter surfaced roadway section.

Column 1	Column 2	Column 3	Column 4	Column 5
Treatment	**Number of Applications Per Year (times/yr)**	**How Often the Treatment is Applied (years between application)**	**Costs Per Application (costs/mile)**	**Costs Per Mile Per Year** **column 2* column 4** **column 3**
Line 1: Seal Coat				
Line 2: Striping and Marking				
Line 3: Patching				
Line 4: Process in place, add aggregate, and reblot				
Line 5: Other ___________				
Line 6: Maintenance Costs Per Mile Per Year (Sum Lines 1 through 5)				
Line 7: Analysis Period (years)				20
Line 8: Maintenance Costs Per Mile for the Analysis Period (Line 6 * Line 7)				
Line 9: Initial Construction/ Last Major Rehabilitation Costs (costs/mile)				
Line 10: Total 20-year Costs Per Mile (Line 8 + Line 9)				

Table 3. Agency costs for gravel surfaced roadway section.

Column 1	Column 2	Column 3	Column 4	Column 5
Treatment	**Number of Applications Per Year (times/yr)**	**How Often the Treatment is Applied (years between application)**	**Costs Per Application (costs/mile)**	**Costs Per Mile Per Year** **column 2* column 4** **column 3**
Line 1: Blading				
Line 2: Regravel				
Line 3: Reshape Cross Section				
Line 4: Spot Graveling				
Line 5: Other ____________				
Line 6: Maintenance Costs Per Mile Per Year (Sum Lines 1 through 5)				
Line 7: Analysis Period (years)				20
Line 8: Maintenance Costs Per Mile for the Analysis Period (Line 6 * Line 7)				
Line 9: Initial Construction/ Last Major Rehabilitation Costs (costs/mile)				
Line 10: Total 20-year Costs Per Mile (Line 8 + Line 9)				

Table 4. Agency costs for stabilized gravel surfaced roadway section.

Column 1	**Column 2**	**Column 3**	**Column 4**	**Column 5**
Treatment	**Number of Applications Per Year (times/yr)**	**How Often the Treatment is Applied (years between application)**	**Costs Per Application (costs/mile)**	**Costs Per Mile Per Year** **column 2* column 4** **column 3**
Line 1: Dust Control				
Line 2: Blading				
Line 3: Regravel				
Line 4: Reshape Cross Section				
Line 5: Spot Graveling				
Line 6: Other ____________				
Line 7: Maintenance Costs Per Mile Per Year (Sum Lines 1 through 6)				
Line 8: Analysis Period (years)				20
Line 9: Maintenance Costs Per Mile for the Analysis Period (Line 7 * Line 8)				
Line 10: Initial Construction/ Last Major Rehabilitation Costs (costs/mile)				
Line 11: Total 20-year Costs Per Mile (Line 9 + Line 10)				

Fill out each line in tables 1 through 4 by entering the requested information regarding maintenance treatments that will be applied over a 20-year analysis period. For example, column 1 lists several treatments that are normally applied to the selected surface type. You are to enter the number of applications of the treatment that are applied each year in column 2. In column 3, enter the number of years between each application of the treatment. For example, if a treatment is applied every 4 years, you would enter a "4" in column 3. Lastly, you must enter the costs per mile for each application of the treatment into column 4. Once these values are entered, you can determine the costs per mile for each treatment on a yearly basis. This value is calculated by multiplying the value in column 2 by the value in column 4 and then dividing by the value in column 3. The resulting value is placed in column 5 for each respective treatment type. It should be noted that not all treatment types have to be utilized in the calculation. Further, if you do not know the typical costs or frequencies associated with a particular treatment, default values are provided in tables A-1 through A-4 in Appendix A of this *Technical Brief*. The default values reflect data collected from the local agencies in the state and have been supplemented with expert opinion from the Technical Panel and research team for this research project. It should be noted that the default initial/major rehabilitation costs do not reflect the costs of upgrading the road from one surface type to another. Therefore, if you wish for upgrade costs to be taken into consideration, the default costs for initial construction/major rehabilitation must be increased by the appropriate amount.

After summarizing the costs per mile per year for each treatment used, the total costs per mile per year can be calculated by summing the maintenance costs per mile per year for all treatment types (this is summarized in line 7 for tables 1 and 4 and line 6 for tables 2 and 3). The maintenance costs per mile for the analysis period can be calculated by multiplying the total costs per mile per year by the length of the analysis period listed in the table (20 years is the default value). The maintenance costs per mile are summarized in line 9 for tables 1 and 4 and line 8 for tables 2 and 3. These final total costs for each surface type can then be determined by adding the initial construction/last major rehabilitation costs (line 10 for tables 1 and 4 or line 9 for tables 2 and 3) to the maintenance costs per mile for the analysis period (line 9 for tables 1 and 4 or line 8 for tables 2 and 3). The total costs should be summarized in line 11 for tables 1 and 4 or line 10 for tables 2 and 3. Final calculated values should be listed on line 4 of the summary table (table 12) that is included on page 14 of this *Technical Brief*.

Example: Using tables 1 through 4, County A determined the agency costs for all surface types as shown in tables 5 through 8. The agency costs for each surface type were determined using the default values found in Appendix A. The agency costs for the HMA, blotter, gravel, and stabilized gravel roads were determined to be $128,400, $74,150, $143,896, and $225,656, respectively. These numbers from tables 5 through 8 have been added to line 4 of the example cost table (table 13) on page 14 of this Technical Brief.

Table 5. Example agency costs for HMA surfaced roadway section.

Column 1	**Column 2**	**Column 3**	**Column 4**	**Column 5**
Treatment	**Number of Applications Per Year (times/yr)**	**How Often the Treatment is Applied (years between applications)**	**Costs Per Application (cost/mile)**	**Costs Per Mile Per Year** **column 2* column 4** **column 3**
Line 1: Crack Sealing	1	3	$1,200	$400
Line 2: Seal Coat	1	4	$7,000	$1,750
Line 3: Overlay	1	20	$37,000	$1,850
Line 4: Striping and Marking	1	4	$280	$70
Line 5: Patching	1	1	$500	$500
Line 6: Other ____________				--
Line 7: Maintenance Costs Per Mile Per Year (Sum Lines 1 through 6)				$4,570
Line 8: Analysis Period (years)				20
Line 9: Maintenance Costs Per Mile for the Analysis Period (Line 7 * Line 8)				$91,400
Line 10: Initial Construction/ Last Major Rehabilitation Costs (costs/mile)				$37,000
Line 11: Total 20-year Costs Per Mile (Line 9 + Line 10)				$128,400

Table 6. Example agency costs for blotter surfaced roadway section.

Column 1	Column 2	Column 3	Column 4	Column 5
Treatment	**Number of Applications Per Year (times/yr)**	**How Often the Treatment is Applied (years between application)**	**Costs Per Application (costs/mile)**	**Cost Per Mile Per Year** **column 2* column 4** **column 3**
Line 1: Seal Coat	1	4	$7,850	$1,962
Line 2: Striping and Marking	1	4	$370	$93
Line 3: Patching	1	1	$1,260	$1,260
Line 4: Process in place, add aggregate, and reblot				--
Line 5: Other ___________				--
Line 6: Maintenance Costs Per Mile Per Year (Sum Lines 1 through 5)				$3,315
Line 7: Analysis Period (years)				20
Line 8: Maintenance Costs Per Mile for the Analysis Period (Line 6 * Line 7)				$66,300
Line 9: Initial Construction/ Last Major Rehabilitation Costs (costs/mile)				$7,850
Line 10: Total 20-year Costs Per Mile (Line 9 + Line 9)				$74,150

Table 7. Example agency costs for gravel surfaced roadway section.

Column 1	Column 2	Column 3	Column 4	Column 5
Treatment	**Number of Applications Per Year (times/yr)**	**How Often the Treatment is Applied (years between application)**	**Costs Per Application (costs/mile)**	**Costs Per Mile Per Year** **column 2* column 4 / column 3**
Line 1: Blading	50	1	$65	$3,250
Line 2: Regravel	1	6	$7,036	$1,173
Line 3: Reshape Cross Section				--
Line 4: Spot Graveling	1	1	$2,420	$2,420
Line 5: Other ____________				--
Line 6: Maintenance Costs Per Mile Per Year (Sum Lines 1 through 5)				$6,843
Line 7: Analysis Period (years)				20
Line 8: Maintenance Costs Per Mile for the Analysis Period (Line 6 * Line 7)				$136,860
Line 9: Initial Construction/ Last Major Rehabilitation Costs (costs/mile)				$7,036
Line 10: Total 20-year Costs Per Mile (Line 8 + Line 9)				$143,896

Table 8. Example agency costs for stabilized gravel surfaced roadway section.

Column 1	**Column 2**	**Column 3**	**Column 4**	**Column 5**
Treatment	**Number of Applications Per Year (times/yr)**	**How Often the Treatment is Applied (years between application)**	**Costs Per Application (costs/mile)**	**Costs Per Mile Per Year** **column 2* column 4** **column 3**
Line 1: Dust Control	1	1	$2,300	$2,300
Line 2: Blading	6	1	$380	$2,280
Line 3: Regravel	1	10	$17,416	$1,742
Line 4: Reshape Cross Section	1	10	$3,400	$340
Line 5: Spot Graveling	1	1	$3,635	$3,635
Line 6: Other ____________				--
Line 7: Maintenance Costs Per Mile Per Year (Sum Lines 1 through 6)				$10,297
Line 8: Analysis Period (years)				20
Line 9: Maintenance Costs Per Mile for the Analysis Period (Line 7 * Line 8)				$205,940
Line 10: Initial Construction/ Last Major Rehabilitation Costs (costs/mile)				$19,716
Line 11: Total 20-year Costs Per Mile (Line 9 + Line 10)				$225,656

Step 3. Determine the User Costs

After determining the agency cost component of the analysis, the next step involves calculating the user cost portion. In this analysis, there are two components of user costs that are considered: vehicle operating costs and crash costs. As mentioned previously, the user cost portion of the analysis may be used in full, used partially, or totally excluded from the analysis. The utilization of user costs in life cycle cost analysis is supported by many agencies including the Federal Highway Administration (FHWA 1998) and it is recommended that the users of this *Technical Brief* also consider user costs.

Step 3a. Determine the Vehicle Operating Costs

The first user costs to be determined are the vehicle operating costs. These costs represent the wear and tear on a vehicle associated with driving on various pavement surfaces. Figure 1 displays the vehicle operating costs per mile of roadway for roads with ADT values of 0 to 1000 vehicles per day. Using figure 1, enter the plot at your known ADT level and determine the corresponding vehicle operating costs for each of the four surface types being considered (HMA, blotter, gravel, and stabilized gravel). These values can be listed on *line 5* of the summary table (table 12) that is included on page 14 of this *Technical Brief*.

Example: Using figure a, County A used an ADT of 350 and drew a line upward through the three surface type cost lines. The vehicle operating cost for the HMA, blotter, gravel and stabilized gravel roads were determined to be $310,000, $375,000, $500,000 and $420,000, respectively. The numbers from figure 1 have been added to line 5 of the example cost table (table 13) on page 14 of this Technical Brief.

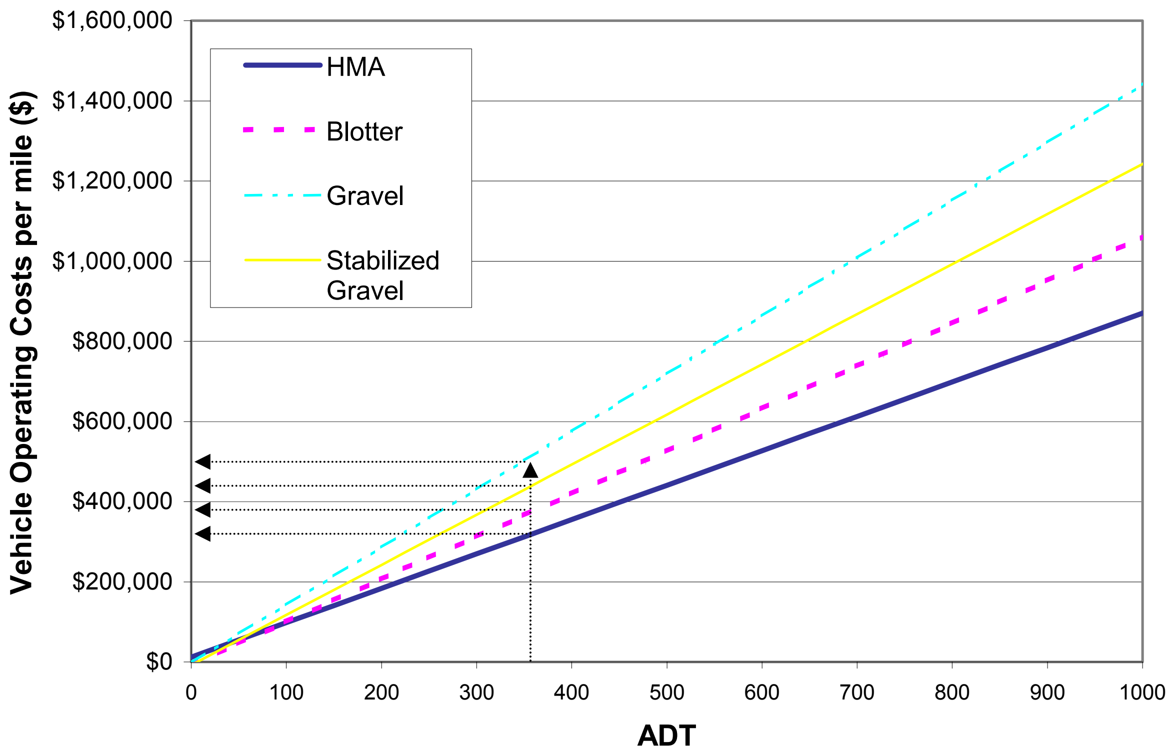

Figure 1. Cumulative 20-year vehicle operating costs per mile of roadway for roads with 0 to 1000 ADT.

Step 3b. Determine the Crash Costs

The second user costs to be determined are crash costs. The crash costs for a given roadway are based upon the frequency of fatal, injury, and personal damage crashes that occur within a given timeframe on a roadway section. Based upon your knowledge of the road section, use table 9 to determine the crash potential you expect per mile of roadway over a 10-year period. While crash potential is provided for a 10-year period, the crash costs were determined for a 20-year analysis period. The crash potential rates were provided for a 10-year period rather than a 20-year period because it is easier to estimate crash potential over a shorter time period such as 10 years versus a longer time period of 20 years. Once the crash potential level is determined for the given pavement section, table 10 can be used to determine the average accident costs for each surface type. These results can be added to *line 6* of the final summary table (table 12) that is included on page 14 of this brief.

Example: Over a 10-year time period, County A expects to have five fatalities, ten injury and ten personal damage crashes over its 5-mile roadway section. The expected crash rates correspond to one fatality, two injury, and two personal damage crashes per mile of pavement over the next 10 years (each crash figure is divided by five to convert the accidents to a per-mile basis). Using *table 9, County A determines that the crash rates for their roadway section correspond to a "medium" crash potential.*

Using table 10, County A determines their "medium" crash potential relates to crash costs of $181,670, $145,420, $73,430, and $38,920, for the HMA, blotter, stabilized gravel, and gravel roads, respectively. The crash costs from table 10 have been added to line 6 of the example cost table (table 12) on page 14 of this Technical Brief.

Table 9. Crash Potential.*

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

*Crash rates based upon 1-mile roadway section.

Table 10. Average 20-year crash costs per mile of pavement per surface type per crash potential level for rural roads.

Surface Type	**None**	**Low**	**Medium**	**High**
HMA	$ -	$ 20,110	$ 181,670	$ 398,900
Blotter	$ -	$ 14,470	$ 145,420	$ 289,860
Gravel	$ -	$ 3,800	$ 38,920	$ 222,300
Stabilized Gravel	$ -	$ 12,250	$ 73,430	$ 275,000

Step 3b. Scale the User Costs

Before adding user costs to the agency costs, it may be appropriate to adjust the user costs. Some agencies discover that during a cost analysis such as this, the very large costs associated with vehicle operating and crash costs often overwhelm the agency (construction and maintenance) costs of a specific project. Therefore, the agency may decide to exclude user costs or reduce the associated costs in order to provide costs that are more in line with expected values. This can be done by scaling the user costs calculated in the previous step with a weighting factor that is representative of the importance of user costs within the agency. A weighting factor of 1.0, for example, is representative of using the user costs as they are calculated (in other words, no scaling of user costs is conducted). A weighting factor of 0 eliminates user costs from consideration in the analysis. Therefore, a reasonable weighting factor should be selected between the values of 0 and 1.0. When selecting the weighting factor, the agency should consider the relative magnitude of the user costs to the agency costs and select a weighting factor that represents the importance of one value to the other. The final weighting factor that is selected should be added to *line 8* of the final summary table (table 12) that is included on page 14 of this brief. If you are not comfortable determining your own weighting factor, table 11 provides a recommended range of weighting factors depending upon the level of importance your agency places on the user costs. Selecting a high level of importance on user costs generally places approximately equal weight on the agency and user costs.

Example: County A wants to place a high level importance on their user costs. Using table 11 as a guide, the county decided to use 0.125 as a weighting factor for the user costs. They add this number to the line 8 of the example cost table (table 13) on page 14 of this Technical Brief.

Table 11. Recommended weighting factors for user costs.

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

Step 4. Summarize Total Costs

The total cost of the three surface types can be determined by filling out the remainder of the cost analysis table (table 12). The total user costs (*line 7*) for each surface type can be determined by adding the vehicle operating costs (*line 5*) to the crash costs (*line 6*). Then the weighted user costs (*line 9*) can be calculated by multiplying the total user costs (*line 7*) by the weighting factor for user costs (*line 8*). Lastly, the total costs for each surface can be determined by adding the agency total costs (*line 4*) to the weighted user costs (*line 9*). The surface with the lowest costs is the most cost-effective choice based solely on economic factors.

Example: County A finalized all of its calculations by computing the total user costs (line 7), the weighted user costs (line 9), and the total costs for each surface (line 10) as shown in table 13 on page 14 of this Technical Brief. County A determined that a blotter road, with the lowest overall total costs, is the most cost-effective surface choice based solely on economical factors.

Table 12. Summary of 20-year cost analysis.

***Line 1.* Road Name**	
***Line 2.* Location**	
***Line 3.* ADT**	

Cost Information	HMA	Blotter	Gravel	Stabilized Gravel
***Line 4.* Agency total costs ($ per mile)**				
***Line 5.* User average total costs– Vehicle operating costs ($ per mile)**				
***Line 6.* User average total costs – Crash costs ($ per mile)**				
***Line 7.* Total user costs ($ per mile) (*Line 5* + *Line 6*)**				
***Line 8.* Weighting factor for user costs**				
***Line 9.* Weighted user costs ($ per mile) (*Line 7* * *Line 8*)**				
***Line 10.* Total Costs ($ per mile) (*Line 4* + *Line 9*)**				

Table 13. Example summary of 20-year cost analysis.

***Line 1.* Road Name**	*County Road A*
***Line 2.* Location**	*5 mile section from B to C*
***Line 3.* ADT**	*350 vehicles per day*

Cost Information	HMA	Blotter	Gravel	Stabilized Gravel
***Line 4.* Agency total costs ($ per mile)**	*128,400*	*74,150*	*143,896*	*225,656*
***Line 5.* User average total costs– Vehicle operating costs ($ per mile)**	*310,000*	*375,000*	*500,000*	*420,000*
***Line 6.* User average total costs – Crash costs ($ per mile)**	*181,670*	*145,420*	*38,920*	*73,430*
***Line 7.* Total user costs ($ per mile) (*Line 5* + *Line 6*)**	*491,670*	*520,420*	*538,920*	*493,430*
***Line 8.* Weighting factor for user costs**	*0.125*	*0.125*	*0.125*	*0.125*
***Line 9.* Weighted user costs ($ per mile) (*Line 7* * *Line 8*)**	*61,459*	*65,053*	*67,365*	*61,679*
***Line 10.* Total Costs ($ per mile) (*Line 4* + *Line 9*)**	*189,859*	*139,203*	*211,261*	*287,335*

Step 5. Evaluate Non-Economic Factors

In some cases, an agency may select a local road surface based solely on the economic factors calculated earlier. However, in most cases, there are other issues besides total costs that come into play when deciding on a roadway surface. These issues include political factors, growth rates, housing concentration/dust control needs, mail routes, and industry/truck traffic. Table 14 has been developed to allow agencies to take both the economic and non-economic factors into consideration. The following directions provide a step-by-step procedure for completing table 14. Each step of the procedure is followed in italics by an example for County A.

1. The first step in evaluating non-economic factors along with cost factors is to assign rating factors to the factor categories in table 14. In order to assign rating factors, you must comparatively weigh the importance of each of the six factor categories and assign higher ratings to those factors that are most important to your agency. The total of all rating factors must add up to 100 percent. You may use any combination of rating factors that make sense to your agency, as long as the sum does not exceed 100. For instance, an agency that places greatest importance on total costs and minor importance to the other factors might assign a rating factor of 50 to Total Costs and 10 to each of the other 5 categories. After the rating factors are selected, they should be added to the *Rating Factors* column in table 14. When applying these rating factors, remember that the same rating factors will be used for each surface type.

   Example: County A decided to weight total cost as having a 55 percent importance because it was the most important factor to them in selecting a pavement surface. However, the County was receiving some political pressure to change the gravel road to an HMA-surfaced road. Therefore, they assigned a 25 percent rating to political issues. At the same time, a 10 percent weighting was assigned to housing concentration/dust control and a 5 percent weighting was assigned to both mail routes and industry/truck traffic. No weight was assigned to growth rates because this issue was not significant to the County. These assignments are shown in table 15.

2. The next step in the evaluation is to assign scoring factors. For each of the six categories, comparatively rank the four surface types by assigning Scoring Factors (4 is highest rating and 1 is the lowest rating) in table 14 for each surface type. A rating of 4 should be assigned to the surface that does best in the given category while a rating of 1 should be assigned to the surface that does worst in that category. If two or more surface types perform equally in a given category, equal scoring factors can be assigned to each.

   Example: Based upon the results of the cost analysis, County A decided to score the Total Costs for each surface with scoring factors of 4, 3, 2, and 1 for the blotter, HMA, gravel, and stabilized gravel roads, respectively. This signified that the blotter had the lowest total cost as determined in the cost analysis (so it received the highest score) followed by the HMA, gravel, and stabilized gravel surfaces. Then, based upon the political pressure to change the given gravel roadway to an HMA-surfaced section, the highest scoring factor of 4 was assigned to the HMA surface and the lowest scoring factor a value of 1 was assigned to both the gravel and stabilized gravel surface types under the political issues factor. Other appropriate scoring factors were assigned to the remaining factor categories as shown in table 15.

3. With rating and scoring factors assigned, the next step of the evaluation is to calculate the scores for each surface type. For each factor category within each surface type, multiply the scoring factor by the rating factor to determine the total score. For this calculation, the rating factor, which previously was given as a percentage, should now be expressed as a decimal (e.g. 5% = 0.05) when multiplying by the scoring factor. The total scores for each surface type should then be determined by adding the total score for each factor category together and recorded in the bottom row of table 14.

   Example: County A calculated its scores as shown in table 15. The result of the analysis shows that the HMA, blotter, gravel, and stabilized gravel roads had total scores of 3.45, 3.55, 1.55, and 1.45, respectively.

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

   Example: Since the blotter road received the highest total score as shown in table 15, County A selected it as the road surface that was most appropriate under the given set of circumstances. The analysis results provide a solid methodology for making a choice of a blotter road over HMA even with the known political influence.

Table 14. Scoring table for economic and non-economic factors.

Factor Categories	**Rating Factor (%)**	**HMA**		**Blotter**		**Gravel**		**Stabilized Gravel**	
		Scoring Factor	**Total Score** (RatingFactor* ScoringFactor)	**Scoring Factor**	**Total Score** (RatingFactor* ScoringFactor)	**Scoring Factor**	**Total Score** (RatingFactor* ScoringFactor)	**Scoring Factor**	**Total Score** (RatingFactor* ScoringFactor)
Total Costs									
Political Issues									
Growth Rates									
Housing Concentration/ Dust Control									
Mail Routes									
Industry/ Truck Traffic									
Total Score	100%								

Table 15. Example scoring table for economic and non-economic factors.

Factor Categories	Rating Factor (%)	HMA		Blotter		Gravel		Stabilized Gravel	
		Scoring Factor	Total Score (RatingFactor* ScoringFactor)	Scoring Factor	Total Score (RatingFactor* ScoringFactor)	Scoring Factor	Total Score (RatingFactor* ScoringFactor)	Scoring Factor	Total Score (RatingFactor* ScoringFactor)
Total Costs	55%	3	1.65	4	2.20	2	1.10	1	0.55
Political Issues	25%	4	1.00	3	0.75	1	0.25	2	0.50
Growth Rates	0%	4	0.00	3	0.00	1	0.00	2	0.00
Housing Concentration/ Dust Control	10%	4	0.40	3	0.30	1	0.10	2	0.20
Mail Routes	5%	4	0.20	3	0.15	1	0.05	2	0.10
Industry/ Truck Traffic	5%	4	0.20	3	0.15	1	0.05	2	0.10
Total Score	100%		**3.45**		**3.55**		**1.55**		**1.45**

Summary

The *Technical Brief* outlines a step-by-step process to assist counties in South Dakota in making road surface type decisions. This manual procedure allows the user to consider any combination of agency costs, user costs, and other non-economic factors when determining the appropriate surface type for a given roadway section. The models used as the basis of this procedure are based upon the average construction and maintenance costs, treatment timings, crash costs, and vehicle operating costs submitted by counties in South Dakota during the data collection efforts of this study with some modifications by the Technical Panel (as noted in the final report for this project). In addition to the manual procedures outlined in this document, a software tool has been developed that is also available for conducting the analysis. The software tool allows an agency to further customize the types of treatments and the costs that will be applied over the life of a road section. The basis for this manual procedure and the software tool are summarized in *Local Road Surfacing Criteria, SD2002-10, Final Report.*

References

Federal Highway Administration (FHWA). 1998. *Life-Cycle Cost Analysis in Pavement Design.* FHWA-SA-98-079. Federal Highway Administration, Washington, DC.

APPENDIX A

DEFAULT TREATMENT COSTS AND FREQUENCIES

Table A-1. Default construction and maintenance costs for HMA roadways in South Dakota based upon ADT levels.

ADT	Initial Const. or Major Rehab. Cost ($)	Crack Seal		Seal Coat		Overlay		Striping and Marking		Patching/ Annual Maint. Cost ($)
		Years between app.	Cost ($)	Years between app.	Cost ($)	Years between app.	Cost ($)	Years between app.	Cost ($)	
0-99	35,000	3	900	5	6,500	21	35,000	5	210	500
100-199	35,000	3	900	5	6,500	17	35,000	4	250	500
200-299	37,000	3	1,200	4	7,000	20	37,000	4	280	500
300-399	37,000	3	1,200	4	7,000	20	37,000	4	280	500
400-499	39,000	5	1,600	4	7,300	20	39,000	4	310	500
500-599	40,000	6	1,600	4	7,300	20	40,000	4	320	500
600-699	43,000	6	1,600	4	7,300	20	50,000	4	360	500
> 700	43,000	6	1,600	4	7,300	20	50,000	4	360	500

Note: All costs are per mile.

Table A-2. Default construction and maintenance costs for blotter roadways in South Dakota based upon ADT levels.

ADT	Initial Construction or Major Rehab. Cost ($)	Seal Coat		Striping and Marking		Patching/Annual Maint. Cost ($)
		Years between app.	Cost ($)	Years between app.	Cost ($)	
0-99	7,000	5	7.000	5	250	530
100-199	7,000	5	7,000	5	250	920
200-299	7,170	4	7,170	4	280	1,250
300-399	7,850	4	7,850	4	370	1,260
400-499	9,180	5	9,180	5	440	1,430
> 500	9,540	4	9,540	3	450	3,150

Note: All costs are per mile.

Table A-3. Default construction and maintenance costs for gravel roadways in South Dakota based upon ADT levels.

ADT	Initial Construction or Major Rehab. Cost ($)	Blading		Regravel		Spot Gravel/ Annual Maint. Cost ($)
		Times per year	Cost ($)	Years between app.	Cost ($)	
0-99	3,700	17	45	8	3,700	350
100-199	3,700	20	45	8	3,700	800
200-299	4,500	30	50	6	4,500	1,070
> 300	7,036	50	65	6	7,036	2,420

Note: All costs are per mile.

Table A-4. Default construction and maintenance costs for stabilized gravel roadways in South Dakota based upon ADT levels.

ADT	Initial Construction/ Major Rehab. Cost ($)	Dust Control		Blading		Regravel		Reshape Cross Section		Spot Gravel/ Annual Maint. Cost ($)
		Years between app.	Cost ($)	Times per year	Cost ($)	Years between app.	Cost ($)	Years between app.	Cost ($)	
0-99	5,000	1	2,700	4	40	12	2,300	--	--	500
100-199	8,154	1	3,300	4	40	5	4,854	--	--	333
200-299	8,154	1	3,300	4	40	5	4,854	--	--	333
> 300	19,716	1	2,300	6	380	10	17,416	10	3,400	3,635

Note: All costs are per mile.