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Improved processes for selection and design of lightly surfaced roads

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Improved processes for selection and design of lightly surfaced roads

by

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GLOSSARY

Annual Average Daily Traffic (AADT): The average total volume of traffic throughout a day

AASHTO: American Association of State Highway and Transportation Officials

ARCGIS: A platform for designing and managing solutions through the application of geographic knowledge

Base Course: The layer used in a pavement system to reinforce and protect the sub grade or sub-base

BSP: Base Stabilization Product

CSAH: County State Aid Highway

Design Period: The number of years that a pavement is to carry a specific traffic volume and retain a minimum level of service

Equivalent Single Axle Loads (ESALs): A numeric factor that expresses the relationship of a given axle load in terms of an 18 kip single axle load

Falling Weight Deflectometer (FWD): A non-destructive and non-intrusive device used in pavement engineering to evaluate pavement structural condition. The FWD is a tool used to achieve rapid and repeatable in-situ characterization of the pavement layer stiffness (DOT, 2008)

GIS: Geographic Information System

Heavy Commercial Annual Average Daily Traffic (HCAADT): The estimate of daily heavy commercial traffic on a road segment that represents the total heavy commercial traffic on the segment that occurs in a one period divided by 365. Heavy commercial traffic is defined as all vehicles with at least two axles and six tires (Mn/DOT-Traffic Forecasts and Analysis Section, 2012)

LST: Light Surface Treatments or Bituminous Surfacing or Surface Dressing

LVR: Low-volume Roads will be defined as local roads with an average daily traffic less than 500

MN/DOT: Minnesota Department of Transportation

NRCS: National Resources Conversation Service

Shapefile: Stores non-topological geometry and attribute information for the spatial features in a data set. Shapefiles can support point, line and area features

Soil (or Sub grade) Factor: A value assigned based to soils based on soil classification. The SF is used to calculate pavement designs

ABSTRACT

This research begins by conducting case study research to determine the current practices of applying light surface treatments (LSTs) on aggregate-surfaced roads in Minnesota. Based on the results of the case study research, a selection guide is developed to select which aggregate-surfaced roads are good candidates for LSTs. The selection guide considers factors such as traffic volume and traffic type, sub grade and sub-base conditions, availability of quality of aggregate and costs of alternative methods for treating aggregate-surfaced roads. The selection guide will include both a GIS model and a decision tree. The GIS model can be used by road officials to make a preliminary assessment to find which roads have the characteristics of a candidate road. Once roads or areas have been identified using the assessment, the decision tree can be used to confirm or refute whether the road is a candidate road. The roads identified by the selection guide were validated using both Henning's (Henning, Bennett, & Kadar, 2007) model and interviews of county engineers. This paper concludes that both Henning's model and the county engineers validated that this selection guide can be used to identify candidate roads. Additionally, the model that was developed can be applied to a number of counties and states in the United States because the requisite GIS data is widely available.

The second part of the research provides recommendations to improve the current practices used to design the road structure supporting a LSTs. Throughout the literature review; it was found that the majority of low-volume road officials in the United States use pavement design methods to design the road structure for an LST. Minnesota was selected as a case study to investigate the current practices of low-volume road officials. In Minnesota the Gravel

Equivalent method, the Mechanistic Empirical method and the AASHTO method are the methods used to design roads with LSTs. These three methods were used to design a stabilized full depth reclamation layer on two case study paved roads in rural areas in Minnesota. The case study road designs show that each method has shortcomings that noticeably affect the road design. It is recommended that low-volume road officials throughout the United States conduct a similar evaluation of the design methods used to design their road structure of LSTs. After these shortcomings have been identified, actions should be taken to address the shortcomings. In conclusion, the research found that a design method should be developed to design the road structure of LSTs specifically for local conditions found in each state of the United States. This design method should be straightforward to implement so it compatible with the workload of a local transportation official and should consider factors such as climate, various surface layers, ESALs and soil support conditions.

CHAPTER 1

GENERAL INTRODUCTION

Paving costs in the United States have noticeably increased due to the increasing prices of raw materials, especially petroleum. According to the bureau of labor statistics, the cost of asphalt has increased by 400% since 1996(PPI Index). Since the paving practices were established when the cost of asphalt was low, the pavement design methods typically specify high thicknesses of asphalt. Additionally, the budget for low-volume road officials is under restraint because revenues from the gasoline tax have not increased proportionally to the increase in demand for paved roads (Liberto, 2013). As a result of these factors, asphalt paving is becoming less economical and officials responsible for low-volume roads are considering alternatives to the current practices. One alternative is to apply a Light Surface Treatment (LST) on the surface of a road base that has not been built with typical hot mix asphalt construction. An LST is defined as a textured surface course less than 50 mm (2in) in thickness (UKDFT, 2011). This alternative is being considered by local road officials when gravel roads require upgrades or when paved roads require major maintenance. Although the LST does not provide structural strength, it does serve as a water-proof membrane. Therefore, LSTs tend to be most successful on roads with bases that have sufficient strength to support the expected traffic loads. The road base could be built using a material that costs noticeably less than a typical asphalt pavement. LSTs have been successfully implemented in central and southern Africa, Scandinavia, south East Asia, and to a lesser degree in the United States (Overby & Pinard, 2007). However, the selection guides and the design methods developed to implement Light Surface Treatments have been developed mainly for environments that are different from those found in the United States. This research will investigate the current methods used in the United States to select candidate aggregate-surfaced roads for LSTs and the design methods used to design the road structure of damaged paved roads. Based on these investigations, the researchers will develop a selection process to choose candidate roads for an LST and suggest improvements for the current design methods for the road structure of an LST.

The application of Light Surface Treatments

This section of the report outlines the advantages, the disadvantages, the implementation process, and the construction considerations of an Otta Seal, Chip Seal, and Cape Seal. The slurry seal is typically not applied as a surface course on an aggregate-surfaced road but it is included in this section to serve as background information for the Cape Seal. These specific LSTs were chosen because these are the LSTs applied in the region of our case study research.

Otta Seals

This light surface treatment derives its name from the Otta Valley in Norway where it was first developed in 1963. An Otta Seal is an asphalt surface treatment constructed by placing a graded aggregate on an application of a relatively soft bituminous binding agent (Overby, 1999).

Advantages

- Allows use of material that may be easier to source in locations where good Chip Seal cover aggregate is not available
- Adaptable design allows for various grades of material quality
- May work better for roads with poorer support conditions due to soft binders(more flexible) and a dense matrix

Disadvantages

- The varying size aggregate is difficult to pass through a chip spreader and as a result the equipment is likely to become damaged over time(Wood, 2013)
- Appealing uniform appearance is difficult to achieve
- Poorer skid resistance than a Chip Seal that is well designed
- Higher volume of aggregate used in comparison to a Chip Seal

Implementation

A bituminous binding agent is sprayed onto the unbound road by the distributor. This is followed by the aggregate spreader spreading the graded aggregate onto the binder agent. A pneumatic tire roller is then used to embed and realign the aggregate chips in the binder.

In an Otta Seal surface, the binder works its way upward through the aggregate interstices, which results in a dense, durable matrix that relies on both mechanical interlock and bitumen binding for its strength (Overby, 1999).Figure 1 depicts a cross-section of an Otta Seal.

Construction Consideration

An Otta Seal is not recommended for areas subject to trucks turning or braking (i.e. intersections). Otta Seals are also susceptible to damage by snow plows. There are fewer contractors in America that have experience constructing an Otta Seal than a Chip Seal. However, Otta Seals can still perform if the quality of the workmanship is low. Immediately after the placement of an Otta Seal, the road will resemble an aggregate-surfaced road. Over the course of time the road will resemble a cold mix asphalt surface. The construction rate of an Otta Seal is typically 40,000 square yards per day. An Otta Seal is typically built with a soft binder which allows the road to accommodate for high deflections (Waters, 2009).

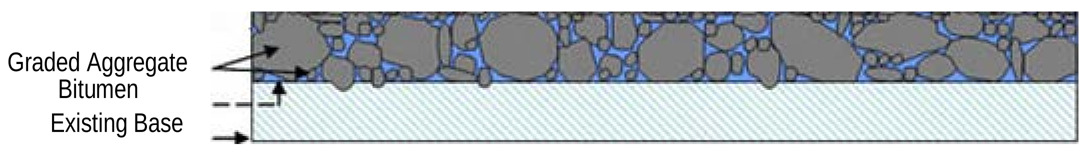


Figure 1:Cross-section of Otta Seal (www.arrb.com.au/sealing/SAsealtype.html) Accessed January 2013

Chip Seal

A Chip Seal (Figure 2) is a pavement wearing course that consists of an application of a binder followed by uniformly-sized aggregate (Caltrans, 2003). A Chip Seal can be used as a surface on an aggregate-surfaced road to reduce dust emission and frequent maintenance.

Advantage

- Less emulsion when compared to Otta Seal
- Chip Seals are typically constructed in a shorter period of time than an Otta Seal

Disadvantages

- Cost competitive only when good quarries are located nearby
- Chip Seals create a rougher surface than an Otta Seal

Implementation

An asphalt emulsion is sprayed uniformly by an asphalt emulsion distributor and then chips are applied evenly by using a self-propelled truck or a truck-attached mechanical spreader. Prior to spraying the emulsion on the road base, a primer must be sprayed on the road base in order for the Chip Seal to adhere. After the chips are applied, the pneumatic tire roller is then used to embed the aggregate into the asphalt film. This light surface treatment produces an all-weather surface that improves skid resistance and seals and protects the underlying road base.

Construction Considerations

A Chip Seal can improve roads with poor friction, reduce the effects of raveling and seal a pavement surface. The performance of a Chip Seal is highly dependent on the workmanship.

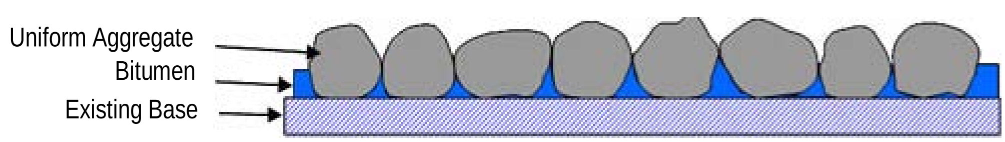


Figure 2: Cross-Section of Chip Seal (www.arrb.au/sealing/SAsealtype.html) Accessed January 2013

Slurry Seal

Slurry Seal is a mixture of an emulsified asphalt (asphaltic oil and water) and crushed rock that can be spread over a chip seal. A Slurry Seal (Figure 3) consists of a graded aggregate, a binder, fines, and additives. The Slurry Seal relies on a combination of mechanical particle interlock and the binding effect of bitumen for strength, similar to that of an Otta Seal. Early trafficking and/or heavy rolling are necessary to develop the relatively-thick, bitumen film around the particles.

Advantages

- One pass is required during the application process
- Roads are open to traffic within hours after construction

Disadvantages

- The equipment used to apply a slurry seal is not as common as that used to apply a chip seal (Yamada, 1999)

Implementation

The slurry mix is applied at the thickness of the largest particle in the mix. The amount of aggregate, filler, additives, and water is based on the mix design. The mix design varies depending on the component materials, environmental conditions, and the existing road surface.

Figure 3: Slurry Seal application (www.fs.fed.us/eng/pubs/html/99771201/99771201.htm) Accessed January 2013

Construction Consideration

Slurry seals are typically applied to paved surfaces with mounted continuous mixing machines however these trucks are difficult to maneuver in restricted areas (American Asphalt Repair, 2012).

Cape Seal

A Cape Seal is a combination of a Chip Seal and a Slurry Seal. The Slurry Seal serves as a wearing course and helps prevent aggregate in the Chip Seal from dislodging from the surface. The Cape Seal prevents more deterioration than either of the treatments individually. The Cape Seal can withstand the heavier loads while being less prone to damage by snowplows.

Advantages

- The Slurry Seal reduces the aggregate loss
- Provides a smooth, black finished product

Disadvantages

- A two-step process that might require the mobilization of two separate fleets of equipment to the job site.
- The cost is higher than any of the other treatments discussed in this paper

Implementation

The construction of a Cape Seal begins with applying a Chip Seal that on the road. After the Chip Seal cures, the Slurry Seal is applied leaving a smoother surface (see Figure 4).

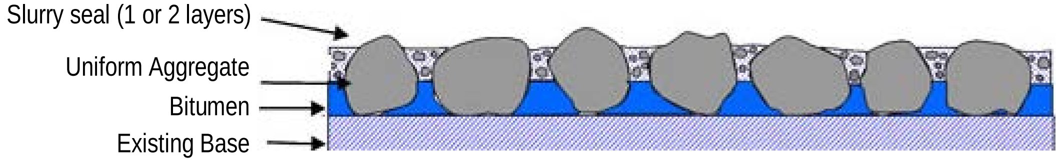


Figure 4:Cross-section of Cape Seal

(www.fs.fed.us/eng/pubs/html/99771201/99771201.htm)Accessed January 2013

Construction Consideration

The use of a Cape Seal would be beneficial if a Chip Seal is considered too rough of a surface course for a particular road. The performance of the Cape Seal is highly dependent on workmanship.

Background Information on light surface treatments

In order to determine which roads are appropriate candidates for light surface treatments, road agencies should understand when conditions are favorable for applying LSTs and the advantages and disadvantages of LSTs.

Here are scenarios that might indicate that applying an LST could be beneficial

- When residents ask for dust control
- If aggregate-surfaced road maintenance is too costly or there is a limited supply of gravel(Greening, Done, Edwards, Jones, Smith, & Ford, 2003)
- If an agency desires to pave a road but does not have the necessary funds for the initial improvement

Below are some advantages of using light surface treatments on aggregate-surfaced roads.

- Provides a weather tight surfacing for unpaved roads
- Provides an improved driving surface
- Construction costs are typically lower than paving a road with asphalt concrete
- Road maintenance of light surface treatment is typically loss costly than road maintenance on an aggregate-surfaced road, especially when traffic is heavy

Below are some disadvantages of using light surface treatments on aggregate-surfaced roads.

- The road condition can deteriorate rapidly if initial distress occurs
- The treatment does not add additional strength to a road

Below are factors to consider when choosing which light surface treatment to build on an aggregate-surfaced road (Overby, 1999).

- Economic and financial factors(life cycle costs)
- Riding quality required
- Characteristics of available materials(aggregate, binder)

- Traffic volumes and traffic loads
- Road slope

CHAPTER 2

SELECTION PROCESS FOR IDENTIFYING CANDIDATE AGGREGATE-SURFACED ROADSFOR A LIGHT SURFACE TREATMENT

A paper to be submitted to the Transportation Research Board

Francis O. Dayamba, Charles T. Jahren

ABSTRACT

Light surface treatments (LST) can be applied on aggregate road surfaces to provide a weather tight bound surface. If an LST is applied according to good practices and on the correct road, agencies can benefit from noticeable cost savings when compared to paving a road or maintaining an aggregate-surfaced road. This research develops a county and state level model to identify roads and areas where LSTs are more likely to succeed. The research shows that geographic information system (GIS) computer software can help identify which roads could be appropriate candidates for LSTs. However, once the software identifies these candidate roads, a site visit should be conducted to confirm these findings. The use of both the GIS model and the site investigation is described as applying the hybrid model. Becker County, MN and Clay County, MN were selected as case studies to validate the county level models developed using the GIS software.

In order to evaluate the model, the research team investigated lightly surfaced roads and documented whether the low-volume road officials considered the roads a success or a failure. The GIS model correctly identified the roads that failed as unlikely candidates for an LST and all the roads in good condition as likely candidates for an LST. Another part of the

evaluation consisted of comparing the hybrid model to another selection guide established by Henning for developing countries.

Both county-level and state-level models showed the ability to identify areas or roads that agencies confirmed would be suitable areas for LSTs.

Introduction

The motivation behind this research is to address a problem faced by road and highway agencies that are responsible for low-volume road networks. These agencies are expected to provide a safe and satisfactory driving experience to the public. Since their budget is restricted, officials must decide which roads are the highest priorities to build and allocate their funds accordingly. Agencies are considering reverting paved roads to unbound surfaces to reduce the cost of maintenance and rebuilding over a period of time. Additionally, the initial cost of paving an aggregate-surfaced road is high and some agencies are reluctant to pave a road with low traffic. An alternative to paving an aggregate road or continuing to maintain an aggregate-surfaced road is applying a light surface treatment (LST). If an LST is applied according to specification and on the correct road, agencies can benefit from noticeable cost savings. A light surface treatment (Figure 5) is defined as a textured surface course less than 50 mm (2inches) in thickness (UKDFT, 2011). An LST is a wearing course that typically consists of an aggregate that is applied with bitumen. Some examples of light surface treatments are Otta Seals, Chip Seals, Cape Seals and Slurry Seals.

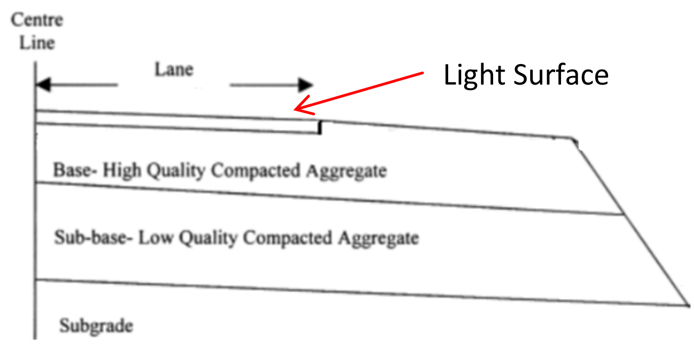


Figure 5: Cross-Section of a light surface treatment

This research develops a county level and a state level model to identify roads and areas where LSTs are more likely to succeed. The system is implemented using a combination of geographic information system software and manual decision aids. The particular software used to demonstrate this system is ARCGIS 10.1. The use of such a system would likely encourage agencies to consider all of the roads in the network and plan how and when to address each unpaved road. Also, the model helps to predict which roads are more likely to have a higher construction cost than the typical Light surface treatment project. This study is designed to identify candidate roads that are located in rural areas in Minnesota. In order to develop this model a literature review, a survey, a questionnaire and case study research are conducted.

Goals and Objectives

The goal of this research is to develop a selection process that road agencies can use to evaluate which areas or aggregate-surfaced roads are candidates for the use of a light surface treatment (LST). The term “candidate” refers to areas or roads where the sub grade soils can provide sufficient support for alight surface treatment so that the LST will last its expected life without requiring excessive sub grade remediation or subsequent road maintenance. The main objective is to develop a hybrid model that requires analysis using a GIS model and a site inspection to determine if a road is appropriate for a light surface treatment. The GIS model will help local road officials consider light surface treatments on a macro-level while the site inspection will help local road officials investigate the site and make a decision based on their findings. The research also discusses techniques that county officials used to improve the performance and decrease the cost of their light surface treatments over time.

When agencies plan to upgrade an aggregate-surfaced road there are a number of options to consider. One option would be to increase the strength of the road base by either adding additional aggregate to the road and/or by adding a base stabilization product. This solution still requires periodic maintenance and the road users would continue to drive on an unpaved road. Another option for upgrading an aggregate-surfaced road is paving the road with concrete or asphalt concrete. However, the initial investment costs for paving a road are relatively high compared to building a light surface treatment. Additionally, the light surface treatment provides an improved driving surface compared to an aggregate-surfaced road. According to the cost data found throughout this research (APPENDIX A COST OF LIGHT SURFACE TREATMENTS), the construction costs to pave an asphalt road is approximately $250,000 per mile while the construction cost to build a light surface treatment in Minnesota is between $20,000 and $70,000 per mile.

Literature Review

The literature review includes other selection guides that were developed to help road agencies decide if a light surface treatment should be applied and which light surface treatment is best for that particular road. Each selection guide focuses on various factors but they all consider the performance and the cost of these technologies over a period of time.

The first selection guide that was reviewed was written by the Matanuska-Susitna Borough in Alaska. The focus of the guide is to determine whether or not to pave an aggregate-surfaced road (McHattie, 2010). The guide outlines a 3-step decision process as follows. The first step prompts the user to decide whether the road needs to be paved. If yes, the next step is to evaluate the foundation, the aggregate-surfaced road surface condition, and the drainage. If no, the user is prompted to use a dust palliative. If the user chooses to pave the road they must ensure that the sub-base/sub grade is in good condition. If it is not in good condition it must be economically feasible to improve the sub-base/sub grade in order to proceed with the decision to pave. The next step is to determine if it is economically feasible to fund the required pavement design for this paved road. If the answer to the previous step is yes, then the guide advises the user to proceed with the paving.

The second selection guide reviewed within this study outlines a process that can be followed in order to assess the demand for a light surface treatment. The six factors considered by Henning (Henning, Bennett, & Kadar, 2007) are topography, climate and soil conditions, traffic volume and loads, community impact, aggregate availability and fugitive dust issues. Then a score sheet is used to assign a score to each of these factors. The sum of these scores is called the grand total. A developed country with a stable government should score a minimum of 12 grand total points before considering an upgrade to an aggregate-surfaced road. A developing country with uncertain funding should score a minimum of 16 points and severely underfunded networks should score a minimum of 21. The study proceeds to help users identify which light surface treatments can be used for the given circumstances and recommends the best light surface treatment based on the net present value (NPV) analysis.

The third selection guide reviewed in this study was developed by Cook (Cook, Petts, & Rolt, 2013). Cook outlines a process towards identifying low volume rural roads (LVRR) that could potentially be rehabilitated or upgraded using a bituminous surfacing. The first step in this guide is to highlight the project needs that relate to pavement or surfacing requirements. The next step is to conduct an assessment of the available funds to finance the project, the road environment, and the available resources to build the project. These assessments should contribute towards determining whether the natural and human resources are compatible with the general project requirements. If the natural and human resources are compatible with the general project requirements then the LVRR is a good candidate for a bituminous surface treatment.

The literature previously mentioned discusses various methods that can be used to decide which roads are most appropriate for an upgrade and/or a Light Surface Treatment. The guides outlined in the literature tend to prompt the user to make a decision based on a flow chart or a calculation. The guide developed in this research is designed to illustrate to the user the critical factors that could affect the performance of the LST. Then it's the user's responsibility to decide whether an LST should be built on the road. The guides outlined in the literature review are designed to be applied in developing countries or tropical environments.

Rural roads in developing countries or tropical environments have different concerns than those built in the United States. This model can be applied to all locations that have access to the requisite GIS data. The model encourages the agency to consider the other roads within the road network when evaluating a road for an LST. The local road agency can weigh the value that each road will have once it is upgraded and use the GIS maps to determine the likelihood that the road will succeed without requiring major maintenance. These are some of the factors that should be considered when ranking all the aggregate-surfaced roads in order of highest demand for an upgrade using an LST. The guides considered in the literature review tend to focus on particular roads without considering the total network of roads.

Methodology-Triangulation of data sources

Case Study Research

The methodology uses various data sources to construct a model that can identify areas or roads where LSTs are more likely to be successful. These sources include a statewide survey of county engineers in Minnesota, a literature review, an in-depth interview with county officials and field visits to sites where LSTs have been applied. According to Yin (Yin K. R., 1994), the most important advantage presented by using multiple sources of evidence is the development of converging lines of inquiry. Yin mentions that any finding or conclusion in case study research is likely to be much more accurate if it is based on several different sources of information. This research uses case study research to identify the factors that are considered when deciding whether to build an LST on an aggregate-surfaced road.

Survey

A survey was distributed to all 87 counties in Minnesota with a goal to better understand the current practices of designing and constructing LSTs and to identify the conditions that make LSTs more likely to succeed. The survey was distributed through Email and through web-based software. Once the initial surveys were answered, phone interviews were scheduled with the county officials that have experience building LSTs on aggregate-surfaced roads. The phone interviews included fourteen questions. Once these questions were answered, the interview continued with an open-ended discussion. The questions included in the survey and the phone interviews are shown in APPENDIX C SURVEY DISTRIBUTED TO

COUNTY ENGINEERS IN MINNESOTA and APPENDIX D INTERVIEW WITH COUNTY ENGINEERS WHO HAVE BUILT LIGHT SURFACE TREATMENTS.

The criteria for selecting a county engineer for the case study research required experience building LSTs on aggregate-surfaced roads and experience using GIS data for other applications within their county. Seven county engineers confirmed that they had such experience. After each of the seven county engineers were contacted two were selected, one that successfully applied LSTs and one county engineer that was unsuccessful. These selections were based on the level of experience that each county official had with LSTs and the level of detail the county official used in the responses to the survey questions.

Becker and Clay counties were the counties selected. These counties are located adjacent to each other in north-western Minnesota as shown in the APPENDIX B. Both counties have a large GIS database that is published on their website and accessible to the public. The access to the county GIS databases was an important factor in the selection process because without that data the author would not have been able to build the model. The comparison is likely to be insightful towards creating a model to help county officials choose roads for light surface treatments.

Interview

A focused interview was used to obtain data through these case studies (Yin, 1994). A set of questions were determined prior to the interviews and once those questions were answered an open-ended discussion was encouraged. The interview was followed by a site visit to obtain observational evidence.

The interviews that were conducted as a part of the case study began by asking the county officials to identify all roads in their county that have been constructed with a light surface treatment followed by identifying roads that they believe are good candidates for light surface treatments. This list of roads was compared to the list that the model generated. This comparison served to validate the model. Then the county engineers and the first author discussed the similarities or the differences between the roads on each list. Throughout this discussion, the researcher team was able to determine the criteria used by the county to determine roads that are appropriate for an LST. Lastly, the research team and staff of the county engineer's office visited the roads treated with LSTs to better understand the site conditions. Throughout these visits, the county official discussed the factors that affect the condition of the LST and whether they perceived the LSTs as a success.

Throughout the interviews, the roads and the areas that the model selected were compared to the roads that county officials thought would be good candidates for an LST. The validation process had as a goal to verify that the criteria established for the model is pertinent in a field application. Another goal of this validation process is to understand how to design the model so it is user-friendly and that it produces an output that county engineers can use to make informed decisions. Low-volume road officials are the intended audience for this research.

Site Visit

Site visits were conducted with county officials to make observations on the environment in which the LST was built and observe the current conditions of the LST. Throughout all the site visits, the various factors were documented: land use in the area surrounding the road, the damage and repairs to the LST (if applicable), main factors that contribute towards the economic success or failure of the road and the aesthetic of each LST. All the LSTs that were built in each county were visited by the first author.

Hybrid Model

The hybrid model involves creating a GIS (Geographic Information System) model followed by a decision tree that is considered after a site visit to the road being considered for an LST.

GIS Model

The county and state level models are designed to map the areas and the unpaved roads that are most likely to be appropriate for a light surface treatment. The first step towards developing these models is identifying all the factors that affect the decision of whether to apply a light surface treatment. The factors that are considered in the GIS portion of the decision process are listed below:

- Soil types likely to support a light surface treatment(Sandy Loam, Loamy Sand and Silty Clay Loam)

- Highlight roads that will not typically attract heavy truck traffic
- Locations that have aggregate sources nearby
- Roads with AADT values between 200 and 500
- Roads that are not located within a municipality
- Roads that are unpaved

These factors were selected to be considered in the GIS model because they address the critical concerns of the local officials and this data can be mapped using GIS software.

County Level (Case Study Becker County)

The model in ARCGIS was developed using shapefiles (.shp). The author chose to use shapefiles because they typically require less disk space and are easier to read and write than other file formats in ARCGIS (ESRI, 1998). The factors considered in the GIS model were chosen based on the findings of the survey, the case study research, the literature review and the GIS data available to county engineers in Minnesota.

Shapefiles required to complete the GIS map

County Boundary of Becker County

http://www.dot.state.mn.us/maps/gisbase/html/statewide.html Accessed March 2013

County boundaries

Roads in Becker County

http://www.co.becker.mn.us/online_services/GIS_data.aspx Accessed March 2013

Select Road.zip

Boundaries of Municipalities throughout the state of Minnesota http://www.dot.state.mn.us/maps/gisbase/html/statewide.htmlAccessed March 2013

Select Municipal Boundaries

Parcels in Becker County

Parcel Shapefile: http://www.co.becker.mn.us/online_services/GIS_data.aspx Accessed March 2013

Classification of Parcels: http://www.co.becker.mn.us/BeckerParcels.zipAccessed March 2013

Soil Type

http://www.co.becker.mn.us/online_services/GIS_data.aspx Accessed March 2013

Select soils.zip

AADT of unpaved roads throughout the state of Minnesota Accessed March 2013

Contact MN/DOT Office of Transportation & Data Analysis or authors of the paper

Aggregate Sources

Contact Office of Materials & Road Research or authors of the paper

Hybrid model to select most appropriate roads
for a Light Surface Treatment

Computer Aided Model-County Level

Part 1: Highlighting areas within a county that are most likely to have candidate roads for a Light Surface Treatment

Step 1. Highlight all areas with soil types that are likely to successfully support a Light Surface Treatment

Step 2. Highlight all areas that will not typically carry heavy traffic and/or agricultural traffic

Step 3. Highlight the various aggregate sources

Part 2: Highlighting roads that are located within areas previously highlighted and the characteristics of an appropriate road for a Light Surface Treatment

Step 1. Highlight roads with AADT between 200 and 500(Limits vary based on county policy)

Light Surface Treatment: Factors to consider

- If the agency has the required equipment and manpower to build a LST, the agency should consider self-preformed construction.
- Designs should be appropriate to the traffic, climatic and terrain environments.(6)
- If a candidate road has an intersection with considerable start and stop traffic, consider paving this intersection with a standard paved surface.
- Apply a chip seal one year(or while the LST is in good condition) after the Light Surface Treatment has been built to prolong the expected life. According to the survey respondents, repairs to Light Surface Treatments are typically expensive.
- Is there a demand for a Light Surface Treatment by the inhabitants for the area? Do they have the means to participate in financially supporting the construction project?
- Areas of weakness are typically the edges and the centerline of the road.

Figure 6: Steps to complete a Computer Aided Model on County-Level

In order to display the factors that were previously discussed in ARCGIS, the author outlines a series of steps towards inputting the data into the GIS software (Figure 6). Below is a justification of all the steps outlined in the county-level model.

Part 1:

Step 1.Based on the interviews of Becker and Clay county officials, it was found that sandy soil types are generally more appropriate than clay soils for the sub grade of an LST. This step outlines how to highlight all the sandy soil types and clay soil types using the ARCGIS software. This step is designed to highlight areas where LSTs have a better chance of lasting throughout their life expectancy. Light surface treatments have been successfully applied on clay soils but for such application to be successful it is usually necessary to increase the strength of the base by adding more aggregate and/or a base stabilization product, applying drain tiles, and repairing localized failures. Such measures to strengthen the roadbed add considerably to the cost, and reducing the likelihood that the project will be economically feasible.

Step 2. Heavy vehicles, in particular agricultural vehicles, tend to damage light surface treatments. If these vehicles drive on the road shoulder they tend to cause damage to the edges of the road. Step 2 outlines how to highlight all the roads where heavy agricultural vehicles are not likely to travel by differentiating between land zoned residential and agricultural. This step infers that there is heavier traffic in agricultural areas than residential areas. However, effort must be invested during the site investigation to ensure that an important amount of the traffic on the road is not heavy traffic. An allowable percentage of heavy traffic will vary based on the light surface treatment. According to the interviews conducted with the county officials, ten percent heavy traffic is the percentage that is appropriate to design their roads.

Step 3. There are a number of inferences that can be made based on the location of an aggregate source. The aggregate sources suggest that heavier traffic would drive on the roads near the aggregate source to haul the aggregate. Roads closer to an aggregate source can be considered for a light surface treatment with the exception of roads that are haul routes. Also, the proximity of gravel pits and quarries to the project location will affect the cost and the decision of which light surface treatment to implement. A cost analysis conducted by the research group has shown that, on average, in the state of Minnesota Chip Seals are less costly than Otta Seals. However, the Chip Seals costs can noticeably increase if the hauling costs are high. If roads are not within close proximity of a high quality aggregate source then it is suggested to use an Otta Seal. Within the computer aided model all the aggregate sources will be highlighted and identified as active or inactive and either as a gravel pit or a quarry.

Another criterion that is used when selecting a candidate road is the road location. If the road is located within a municipality, there is a high likelihood the road will be subject to constant start and stop traffic. If the LSTs are subject to heavier vehicles that start and stop continuously, there are chances the LST will be damaged.

Part 2

Step 1. If an aggregate-surfaced road can structurally withstand the traffic load, then that road can be a good candidate for a light surface treatment. Jahren and Johnson (Jahren & Johnson, 2005)conducted research suggesting that most decision makers upgrade unpaved roads in Minnesota when traffic exceeds 200 AADT and in some cases upgrades are warranted if the traffic exceeds 100 AADT. This number can vary by county, because counties have various limits for traffic volumes that are considered to be acceptable for aggregate-surfaced roads. The general limits considered in this study are 200 to 500 AADT, but these limits are subject to change based on the local conditions. If there is a high demand for a light surface treatment by the road users, then roads with an AADT below 200 might be improved using an LST. This social factor can be critically important when choosing a candidate road for an LST. Aggregate-surfaced roads with an AADT higher than 500 can also be candidates for an LST as long as the base and the sub grade have high strength and the traffic on the road should has a low percentage of trucks. All these steps were completed in ARCGIS for Becker and Clay counties and are illustrated in the following figures: Figure 8, Figure 9, Figure10 and Figure 11.

Decision Tree

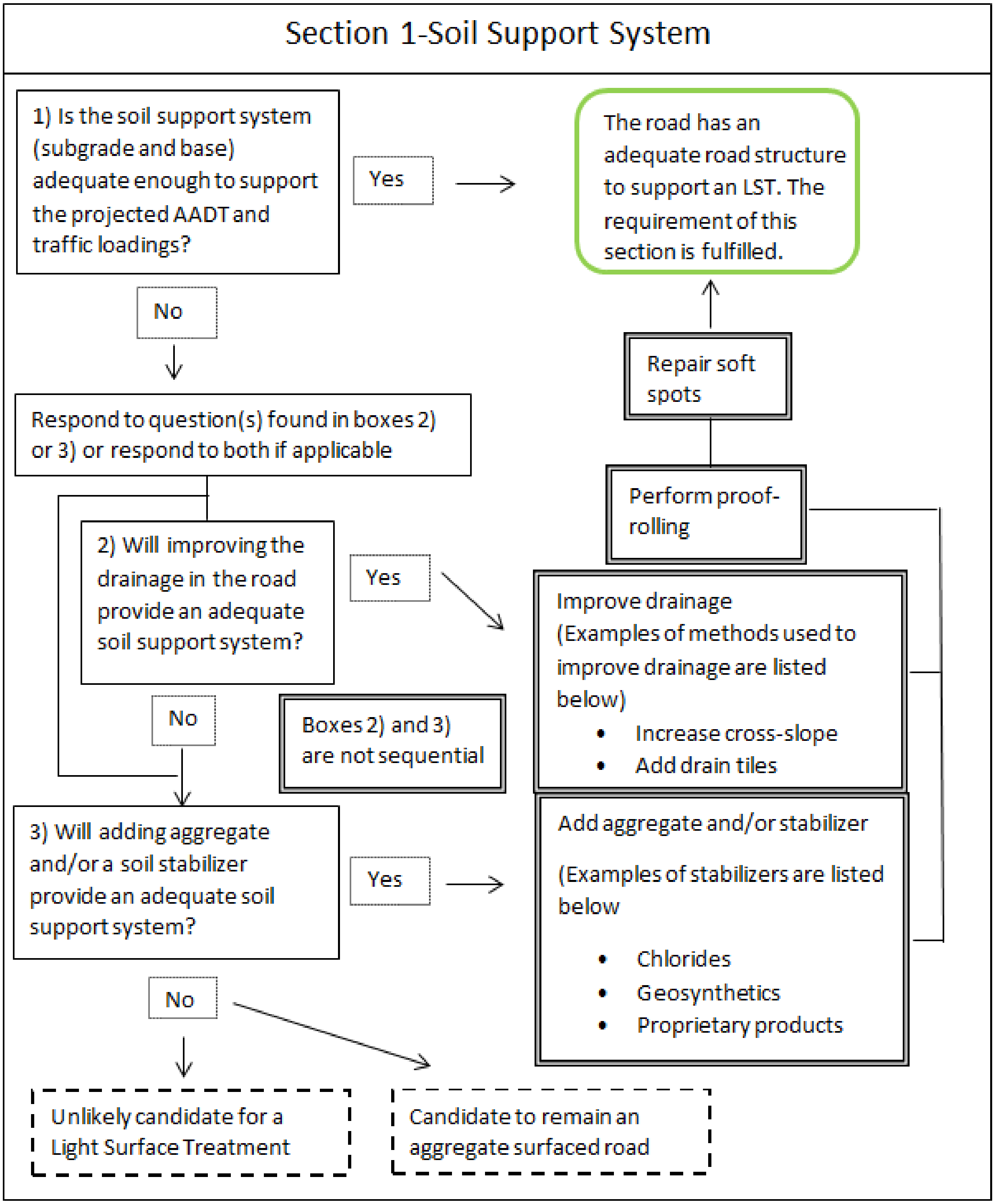
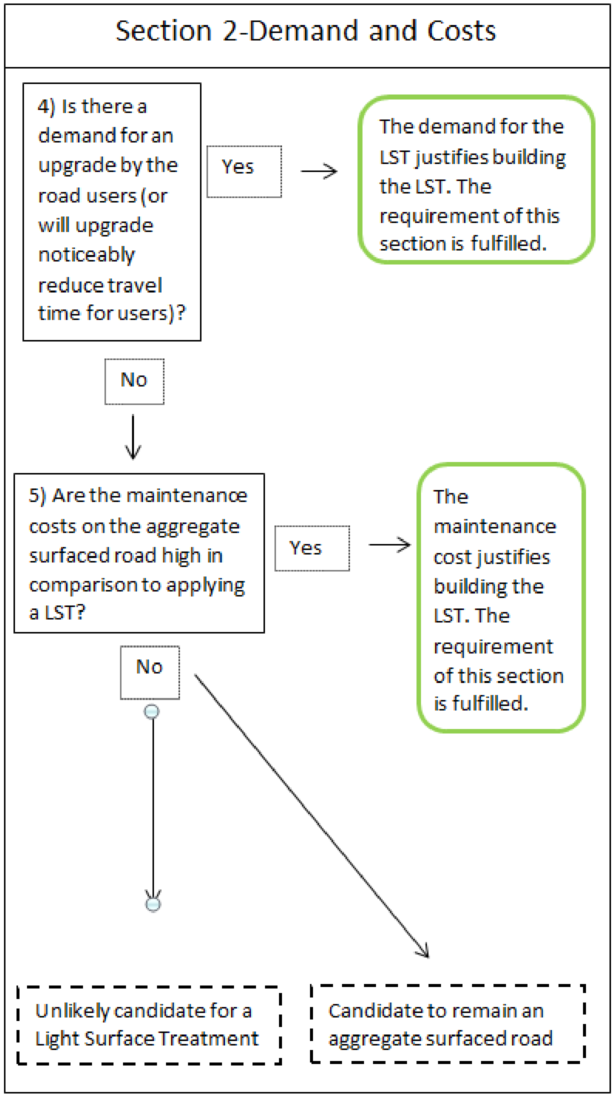
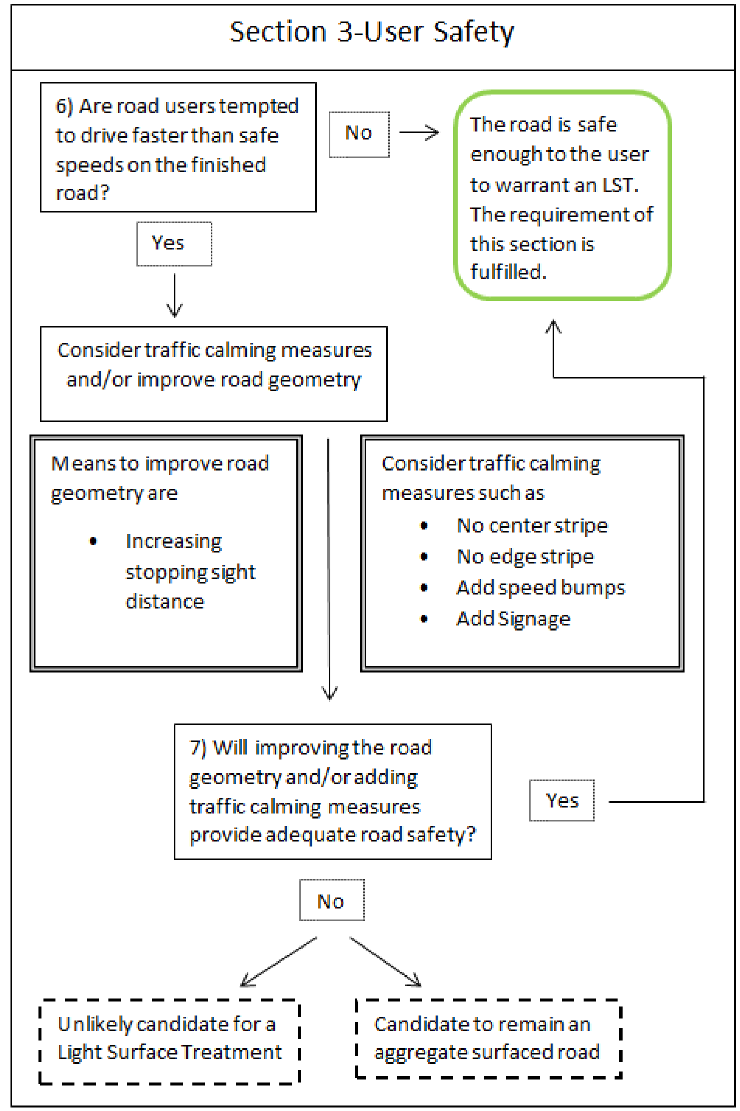


Figure 7: Decision tree to conduct during a site

Figure 7 continued





The purpose of the GIS model is to identify roads or areas that are potential candidates for an LST. The decision tree serves as a means to evaluate whether these candidates roads are appropriate for an LST. In order to apply the decision tree, the local road officials must conduct a site visit to ensure that a road has the correct conditions to successfully support an LST. The decision tree is structured into three sections that address the soil support system, the user demand for an LST, the costs of an LST, and the user safety. All three sections must confirm that the road is a candidate road before further action is taken to implement an LST. If one section does not confirm that it is a likely candidate, then the decision tree infers that the road is not considered a likely candidate road. Each section includes questions to prompt the user to investigate various aspects of the condition of the road and makes recommendations on how to improve roads with unfavorable characteristics. Below is a discussion of the questions and recommendations included in each section.

Section 1: Soil Support System

1) The soil support system is arguably the most important factor to be addressed in order to ensure the success of a light surface treatment. If the soil support is adequate then the user no longer needs to respond to any other question in this section. If the soil support system is not adequate, then the decision tree suggests two different methods to address this situation. These methods are improving the road drainage and adding strength to the road.

2) Road drainage (Pinard, 2011) is also an important factor that must be considered in order to ensure the success of an LST. To improve the drainage properties of a road, tile drains can be installed under the road with clay soils. Another method to improve the drainage of a

road is to build the crown at a cross slope which allows for the water to run-off. According to the (EPA, 2003), the recommended crown is approximately a rise of ½" per foot.

3) Adding aggregate or a base stabilizer are both strategies that county engineers in Minnesota have implemented when building an LST. Some counties applied the aggregate followed by a base stabilizer to provide more strength to the road.

In order to determine whether the aggregate-surfaced road is structurally adequate, an effective strategy is proof rolling. This consists of driving a heavy truck with a known load repeatedly on the road looking for signs of failure. If the road ruts during the testing, the damage can be graded out and the road is eliminated for consideration as a candidate road for an LST.

The LSTs do not provide additional strength to an unpaved road. According to the interviews that were conducted, the AADT tends to increase once a light surface treatment is applied to an unpaved road. As a result, if the current traffic count cannot be structurally supported by the road then careful consideration is required before for an LST is applied.

Section 2: Demand and Costs

The interviews and the surveys have shown that two reasons local road officials consider building LSTs are the demand for an upgrade by the road users or the high costs associated with maintenance of an aggregate-surfaced road.

4) The road users typically complained about the dust of an aggregate road or the high operating costs of using a vehicle on aggregate roads. Some county engineers considered upgrading an aggregate-surfaced road if building a road with an LST would provide a more direct route for road users to reach a paved road.

5) Aggregate-surfaced roads that require higher maintenance costs or are difficult to maintain can be good candidates for an upgrade. The options typically considered by low-volume road officials in developed countries are either an LST or paved surface. Neither of these surfaces requires additional aggregate or routine blading and a result the maintenance costs tend to decrease once an aggregate road is upgraded. Becker County calculates the maintenance costs/mile of each aggregate-surfaced road within their jurisdiction and chooses good candidates for light surface treatments based on these costs. For example, the aggregate-surfaced road with the highest blading cost (includes smoothing surface and resurfacing) in Becker county is CO 158 at $4,317/ mile per year. If a road does not have high maintenance costs the road can still be considered for an LST; however, roads with a higher maintenance cost should be given priority.

<u>Section 3: User Safety</u>

6) and 7) There are some LSTs that road users can confuse to be standard paved roads to a road user who is unfamiliar with LSTs. As a result, road users increase their speeds and use the roads as if they were paved roads. If the road retains the alignment of a low speed aggregate road, it could be problematic. Another problem to consider is that aggregate-surfaced roads with an LST do not provide the same strength or traction as a paved road and this could lead to a safety hazard or damage to the road. During the construction of LSTs, particularly Otta Seals, construction joints usually occur at each point that a truck empties an aggregate load on the bitumen and another truck begins placing aggregate on the bitumen. As a result, roads with lower speed limits can be considered a good candidate for a light surface

treatment. Roads that wind or are located in residential areas are examples of roads that would not encourage high speeds.

In order to prevent users from travelling at high speeds, the decision tree recommends traffic calming measures or improving the road geometry.

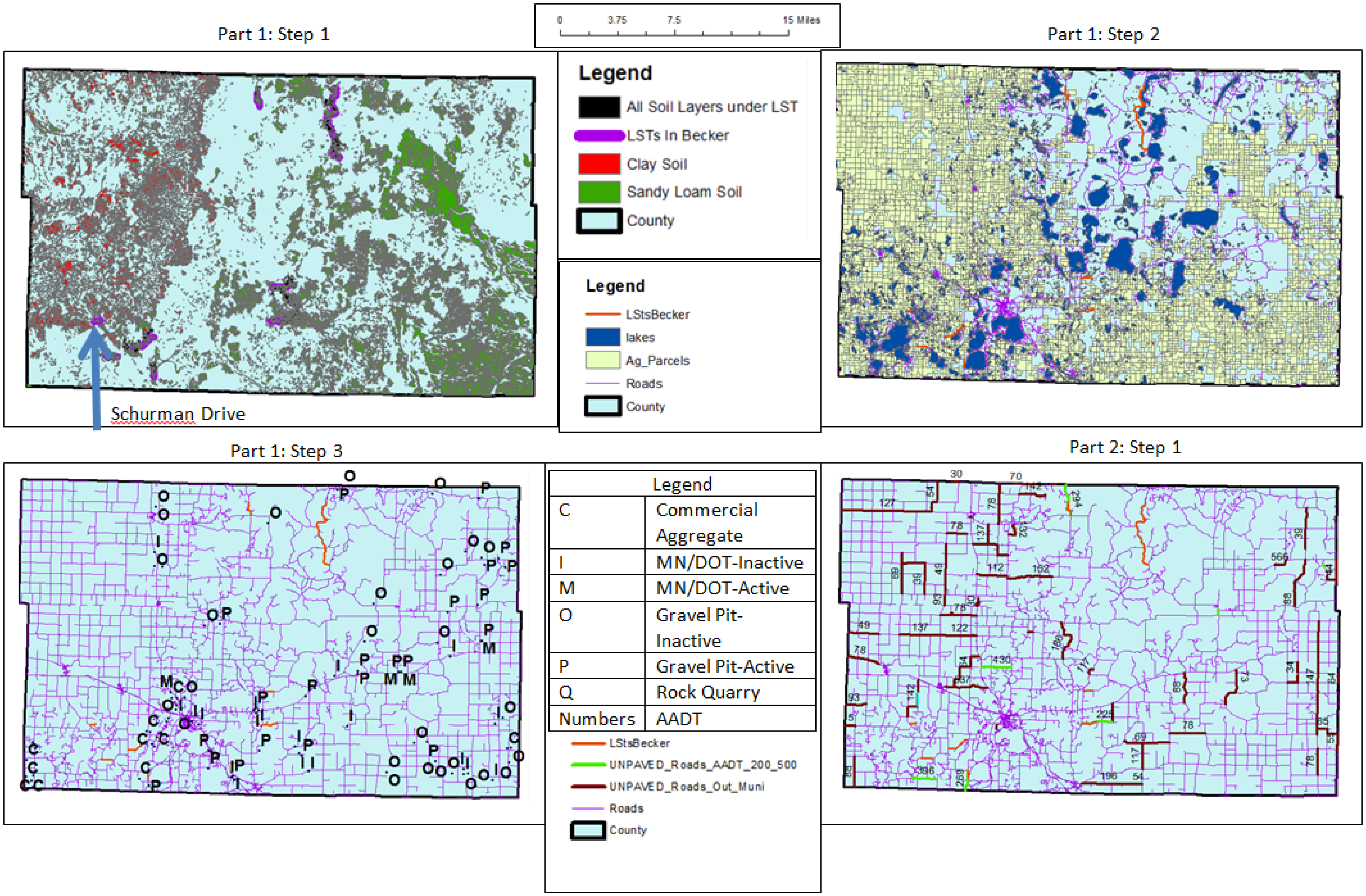


Figure 8: All Parts in Computer Aided Model for Becker County

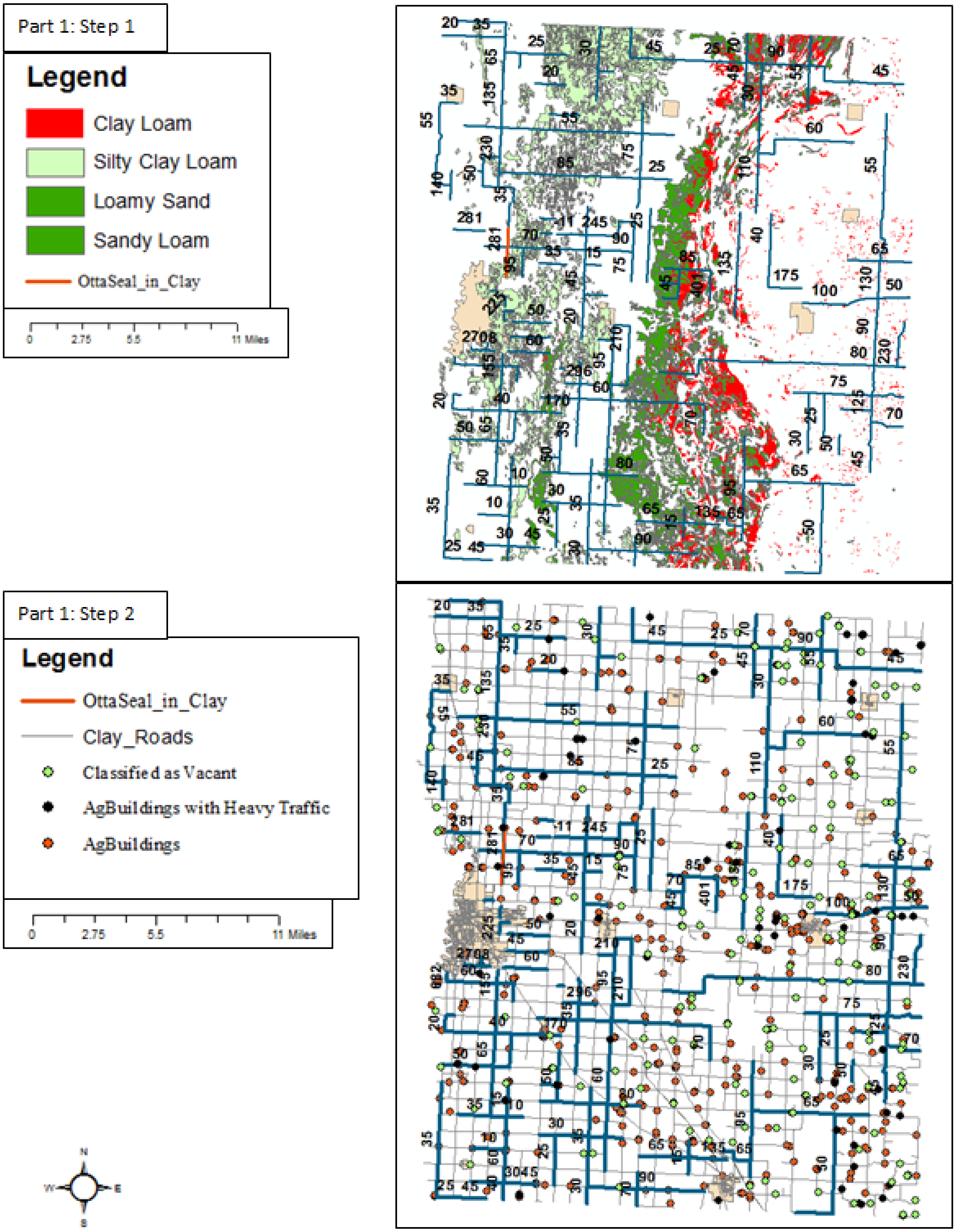
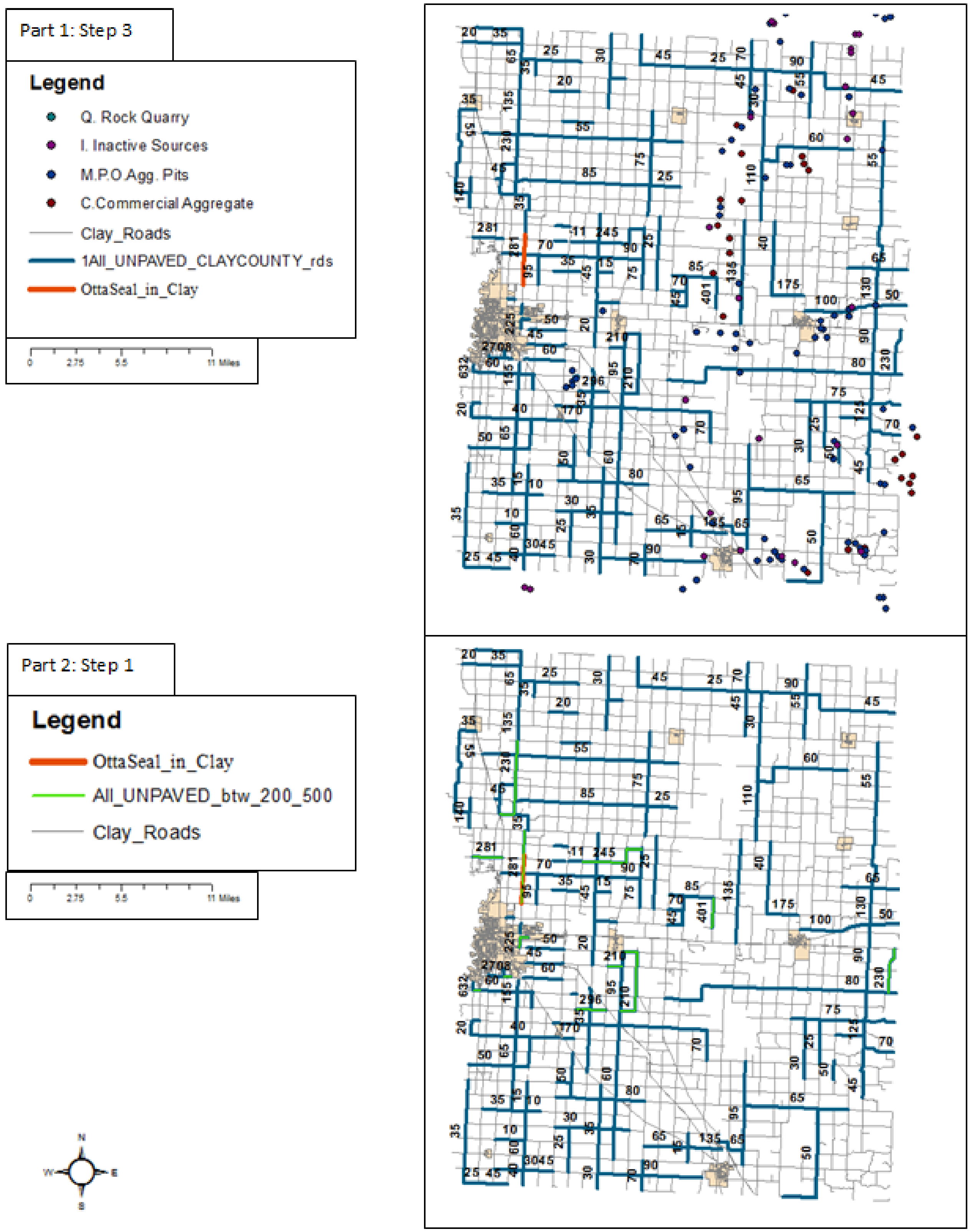


Figure 9: All Parts in Computer Aided Model for Clay County

Figure 9 continued



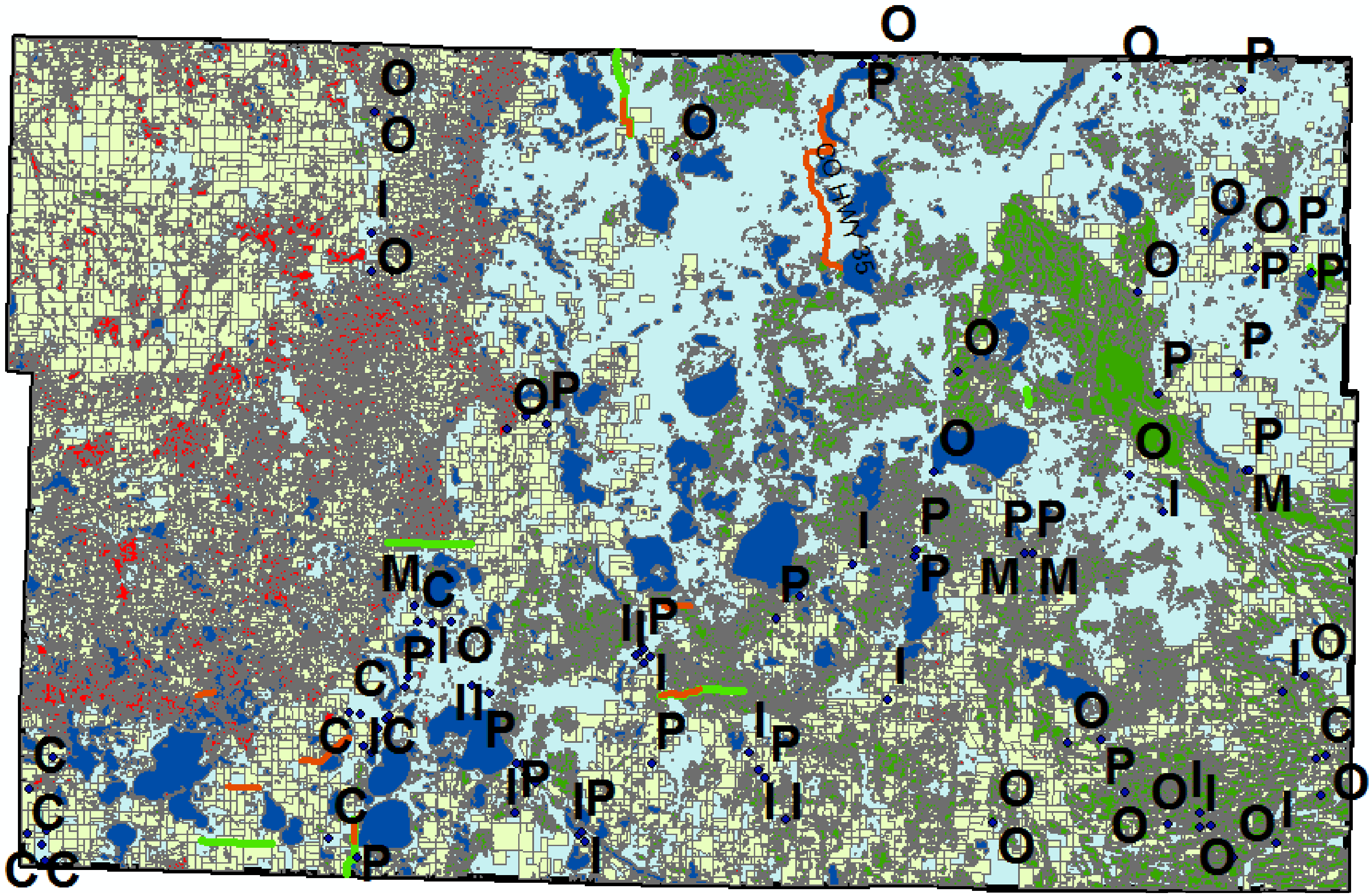


Figure 10: All steps in the Computer Aided Model on the County Level (Becker County)

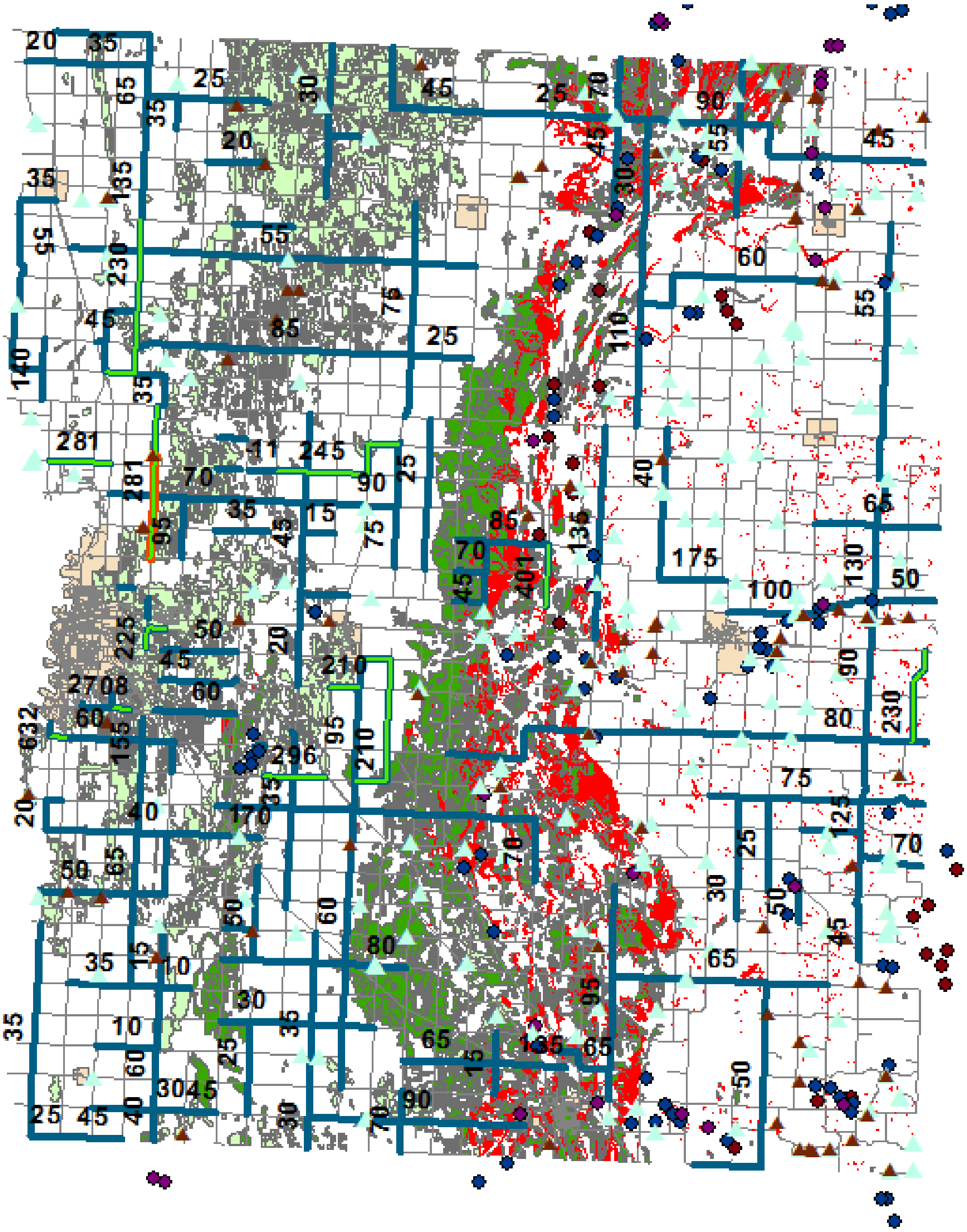


Figure 11: All steps in the Computer Aided Model on the County Level (Clay County)

Note: Legends for

Figure10 and Figure 11 are found in APPENDIX H LEGENDS FOR Figure10

State Level (Case Study Minnesota)

<u>Shapefiles required to complete the GIS map</u>

The state level model provides information that allows local road officials to recommend the most appropriate areas within the State of Minnesota for the use of light surface treatments. It is important to note that it may be possible for light surface treatments to be applied successfully in areas that are not highlighted by the model. However, the highlighted areas represent areas with similar characteristics to areas where LSTs have been successful in the past. An LST is most likely to be successful if it is more cost effective than alternative treatments, provides its intended value to the road users and lasts the duration of the treatment's expected life without requiring major maintenance. From a state-level, the factors that are considered in the model are listed below:

Soil Types: Sandy Loam, Loamy Sand and Silty Clay Loam

Roads: AADT ranges between 200 and 500

Location (Areas with low heavy traffic): Not within a municipality

<u>Soil Type Data</u>

Contact (USDA) NRCS Minnesota state office or authors of the paper

<u>AADT of unpaved roads throughout the state of Minnesota</u>

Contact MN/DOT Office of Transportation & Data Analysis or authors of the paper

<u>Aggregate Sources</u>

Contact Office of Materials & Road Research or authors of the paper

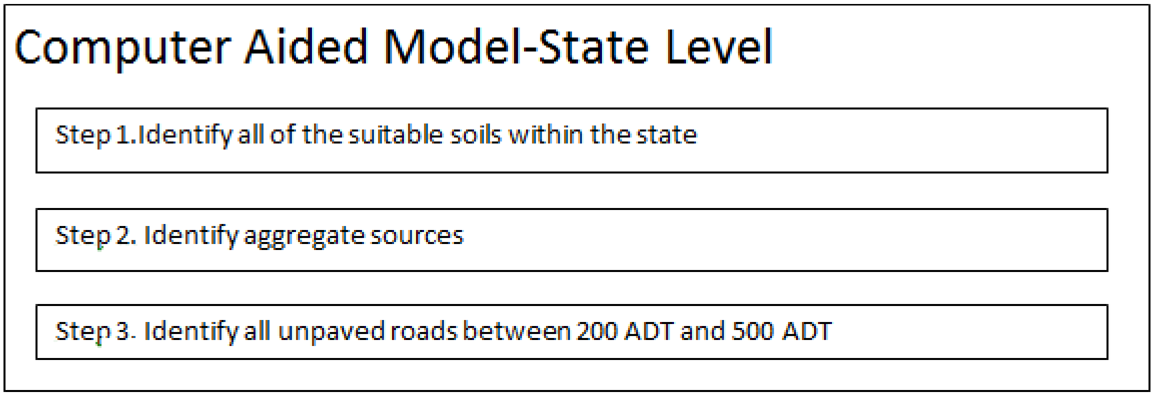


Figure 12: Steps to complete a Computer Aided Model on a State-Level

Results and discussion

Case Study Research

Clay county and Becker county were chosen as the counties to use as a case study for this research project. Clay, Becker, Cass and Saint Louis counties are the only counties amongst the counties that responded to our survey that offer shapefiles that are freely accessible on their website. As a result, these four counties were the only counties within Minnesota that fit the criteria required by the research team.

Survey

The survey was distributed to all 87 counties in Minnesota. Thirty-six counties responded to the survey, 9 of which mentioned that they had experience building light surface treatments on aggregate-surfaced roads. These counties are Becker, Itasca, Clay, Wabasha, Stevens, Cass, St. Louis, Olmsted and Kandiyohi.

The research team did not define the terms "success" or "failure" because the author wanted to find out how the local road officials defined these terms in the context of applying LSTs. Throughout the survey it was found that some counties defined the success of an LST differently than others. The majority of counties deemed that an LST is successful if it is the best economical solution to upgrade an aggregate-surfaced road. Another opinion by the county engineers is an LST is successful if it remains in good condition, without major maintenance, throughout its expected life.

Table 1: Respondents to the survey with experience building an LST on aggregate-surfaced roads

Counties	What LST did county?	What year did they apply LST?	Success or Failure?
Becker	Otta Seal	Once a year since 2004	Success
Itasca	Otta Seal	2003	Neither*
Cass	Otta Seal	2001 and 2002	Success
Wabasha	Otta Seal	2007	Success
Clay	Otta Seal	2008	Failure
Kandiyohi	Otta Seal	2012	Success
St. Louis	Otta Seal	1998	Success
Stevens	Chip Seal	2001	Failure
Olmsted	Otta Seal	2008	N/A

*Itasca County found that the cost of applying an LST was roughly equal to the cost of treating an aggregate surface road with magnesium chloride.

Phone Interviews

The survey was followed by a phone interview with a county official from every county that responded to the survey and they discussed the experience they had applying LSTs.

Table2 shows the responses of two of the counties that were selected for the county visits.

Table 2: Results of survey in Becker and Clay County

Questions	Becker County	Clay County
1. Circle one treatment that has been applied on an aggregate-surfaced road	Double Otta Seal	Double Otta Seal
2. In what month and year was the LST applied on the road?	July 2004	September 2007
3. Road Name	County Road 120	Clay County Road 95
4. Road Location	6 miles E of Detroit Lakes, MN	From clay county state Aid(CSAH) 18 to 70 aver N.
5. LST segment length and Road width	1.5 miles (22' wide)	2.33 Miles(24-26' Wide)
6. Describe Traffic type and provide ADT of road	Low-volume; recreational and residential traffic; 230 ADT	There is a rural subdivision on the LST segment, heavy agriculture traffic, and many large farm implements that use the roadway
7. What work did the crew do in order to prep the base for construction	Average Aggregate-surfaced road	We added 3"-4" of class 5 aggregate surfacing and mixed in a stabilization chemical (Base One). We also drain tiled a portion.
8a. Was the treatment a Success or Failure? Discuss your answer	8 Years old & only 1 Chip Seal applied one year after Otta Seal and minor patching	Both. In the areas of heavy Ag. Traffic, the road has required significant patching. In the areas where farming traffic is lighter, it has performed adequately.

Table 2 continued

8b. Benefits and Disadvantages of LST	Benefits: • Dust Control • Better driving surface • Winter road maintenance is less costly Disadvantages: • Likely to be damaged if heavy traffic frequently drives on the road	Benefits: • No dust • All weather-surface • Less frequent maintenance Disadvantages: • Higher Maintenance costs • When it fails, only remedy is asphalt patching • When it fails, dangerous potholes are created
9. What type of aggregate was used (Include size, shape)? Was the aggregate obtained from a local source?	MN/DOT 3138 OS.1	Local aggregate
10a. Thermal Cracks	Minimal	Minimal
10b. Rutting	Minimal	Minimal
10c. Maintenance Needs	Minor	Patched shoulders and intersections in numerous locations
10d. Maintenance Applied	Chip Seal in 2010	
11. Cost per Mile of LST	\$36,600 (2010)	\$75,544(2007)
12a. Application Rate	HFMS-2S at 0.5 GAL/SY per lift	0.5 GAL/SY per lift
12b. Equipment used to spread aggregate	Chip Spreader	Chip Spreader
12c. Was a pneumatic roller used?	Pneumatic roller(2) used	Pneumatic roller(3) used @ 3mph
13a.Surface	2 Lifts Otta Seal	2 Lifts Otta Seal

Table 2 continued

13b. Base	4"-6" Class 5-2" treated with base stabilizer	6"-7" of Class 5-2" treated with base stabilizer
13c. Sub-base	N/A	Native soils with top soils. Very weak and high moisture
13d. Sub grade	Sandy or Sandy Loam- Approximate R value of 70	N/A
14. Were specifications for the Light Surface Treatment?	Yes, MN/DOT specifications for Bituminous Otta Seal	Yes, we specified a gradation of the Otta Seal aggregate and the number of rollers, speed, and rolling duration. We also specified the oil.
15. Comments/Concerns	Approximately 1 mile of Otta Seal almost every year since 2004 on county and township roads	County forces were used to prep the road. This is the first Otta Seal to be built in this county.

Becker County found Otta Seals to have been successful on their roads but Clay County found they did not get the results that they anticipated. The survey and the phone results (Table 2) showed that there are a number of differences between Becker County and Clay County that affected the success of LSTs. Two of the most important differences are the traffic type on the roads and the base/sub grade beneath the roads. According to the phone interview, the road considered in Becker had an ADT of 230 and the traffic type is typically residential. Whereas in Clay County there were a number of large farm that used heavy implements surrounding CO 95 that resulted in a high percentage of heavy traffic on the road. Also, the soil conditions beneath the road were favorable in Becker County whereas the soils beneath the roads in Clay County consisted mainly of clay. Clay soils tend to require additional support in order to provide sufficient strength for the LST to be successful. Becker County has sandy loam soils which seemed to work well for the LSTs. Another factor to consider is the years of experience that each county has applying LSTs. Becker has been applying LSTs annually since 2004, however, the LST reported by Clay County was the first LST applied in their county. Another difference between the two projects is the construction costs. Becker County built their Otta Seals at $36,000/mile where Clay County built their Otta Seals at $75,000/mile. The emulsion tends to be the highest cost on an Otta Seal project, but both projects used the same HFMS-2S oil. The cost difference is mainly due to the fact that Becker County self-performs their work. Clay County doesn't own the requisite equipment and they don't employ a large enough crew to self-perform the work. Instead they are obliged to contract the work and borrow equipment from neighboring counties. As a result, the costs increase noticeably. Clay County also added 2" more of aggregate to the base than Becker County and added drain tiles beneath the road because of their soil conditions.

Interview Results

One of the focal points of the interviews with the officials from Becker and Clay counties was the discussion of roads with light surface treatments that failed.

Table 3: Roads in Becker County with an LST

	Roads Name	County	Traffic Type	Area Description	Road Condition
1	Golf Course Road	Becker	Residential	4-5 house and golf course	Good
2	West Common Road	Becker	Residential	3-4 houses	Good
3	CO 147	Becker	Residential	Agricultural fields	Good
4	Deroxe Road	Becker	Residential	2-3 houses	Good
5	Schurman Drive	Becker	Residential- Some heavy trucks	5-6 houses	Severely damaged
6	North Pearl Lake Road	Becker	Residential	4-5 houses	Good
7	County Road 95	Clay	Heavy Traffic	5-6 houses	Severely damaged

In Becker County, the only lightly surfaced road to fail is Schurman drive. Schurman drive is a township road that is located just outside a residential community. The main reason for the failure of the road is the weak sub grade conditions. Concrete trucks and dump trucks used this road to access a construction site and these heavy vehicles also contributed to the failure. The primary mode failure of the road was alligator cracking. The county attempted to repair the road by paving the road with asphalt but these areas eventually failed as well (Figure 13).

Figure 13: Picture to show failure modes of Schurman Drive-Picture by Francis O. Dayamba

County road 95 in Clay County was described as a failure by a county official because of the severity of the damage on the road. The main reasons that the road failed are the weak sub grade conditions and the large number of heavy vehicles that used this route. The sub-base is mainly clay soils and clay does not provide good drainage. As a result, the road became water saturated and soft which did not support this LST. CO 95 is also a route that agricultural trucks take to travel towards Moorhead, a metropolitan area. The combination of these factors resulted in the road failing prior to the expected life.

Figure 14: Picture to show failures of CO 95-Picture by Francis O. Dayamba

Key points about LSTs that were discovered throughout the interviews of Becker County and Clay County officials are listed below:

- These counties considered that an important factor towards the success of an LST is the condition of the sub base and sub grade
- High aggregate-surfaced road maintenance costs is a critical factor towards selecting a road for an LST
- Counties that have the equipment and resources to self-perform the LSTs will spend considerably less than counties that bid the work
- Repairs of LSTs result in high cost
- There are only a limited number of ways to repair LSTs within these counties
- Areas of the road that are susceptible to damage by heavy traffic and snow plows are the edges and the centerline

- Innovative ways to partly finance projects are to solicit funds from FEMA or inhabitants that live in the surrounding area
- The traffic count tends to increase on a road that is upgraded from an aggregate-surfaced road to an LST
- Uses of LSTs
    - The traffic count may increase to the point that paving the road is justified
    - Bridge gap between two paved roads

Results and Analysis using the GIS model

County Level-Becker County

The map shown in Part 1: Step 1 of Figure 8) shows that the western side of Becker County has a considerable amount of the clay soil type. The central and eastern regions of the state have a considerable amount of sandy loam, loamy sand, and silty clay loam. According to the literature and the surveys, clay soils are challenging soil types for light surface treatments while sandy loam, loamy sand and silty clay loam seem to be more favorable. Figure 8 show that Schurman Drive is the only road that was built with a light surface treatment that is located in an area with predominantly clay soils. Schurman Drive is also the only road out of the six that have used an Otta Seal which has been subject to significant damage. When Schurman Drive began to fail, county personnel removed sections of the LST and patched those sections with hot mix asphalt. Eventually the patched sections began to fail as well. One county official believes that this failure is due to the types of soil beneath the road. The LSTs built in Becker County are mainly built in the central part of the county. The types of soils in that area are mainly loam, sandy loam, and muck. Muck soil is an organic fine-grained soil that is black or dark brown with various proportions of sand, silt, and clay (NYSDOT , 2013).

There is a trend that shows that the central areas of the county are the most appropriate areas for an LST. The central areas of the county have soil types that are not primarily clay, have a low portion of agricultural parcels, and have aggregate sources close enough to the areas so that the hauling costs are not excessive. Becker county officials also chose to build the LSTs in the central areas of the state so the model has proven to corroborate the actions of the Becker county highway agency. A conclusive decision on whether to apply an LST cannot be made using the GIS model if the area has a considerable amount of clay soil and has a low density of agricultural parcels. In such a case, county officials should conduct a site investigation in such areas.

The map shown in Part 2: Step 1 outlines all the unpaved roads in Becker County that are within the range of 200 -500 AADT. There are three roads that Becker County upgraded with an LST that fit all the criteria highlighted in every step of the GIS model. There are some roads that have been upgraded using an LST that did not exist in the AADT shapefile. The AADT data lacks accuracy and as a result there are unpaved roads within Becker County that are not highlighted in the model.

The roads that were selected by the GIS model as being appropriate roads for LSTs are listed in Table 4.

Table 4: County roads identified as candidate roads for LSTs in Becker County

County Roads selected for LST	Roads upgraded using an LST
CO 120	Yes
CO 158	Yes
CO 39	No
CO 138	No
CO 147	Yes
CO 50	No

County Level-Clay County

The map shown in Part 1: Step 1 (Figure 9) shows that the majority of clay loam soils run throughout the central part of the county and the rest of the clay loams soils are scattered on the east of the county. There is a section, located in the central part of the county, of sandy loam and loamy sand soil that runs transversely throughout the county. On the west side of the county, there is silty clay loam soil that runs transversely through the county. Other counties throughout the state of Minnesota had success applying LSTs on silty clay loam soil. However, the road that was improved with an LST was located in this area and is considered a failure by county officials. Throughout the interview, the county official stated that the western section of the county, which has a considerable amount of silty clay loam, did not have soils that he deemed to be appropriate for an LST. The county official mentioned that the areas highlighted as sandy loam and loamy sand does appear to be good areas for improving a road with an LST.

The map shown in Part 1: Step 2 (Figure 9) shows that the agricultural buildings are scattered throughout the county. The building data is used instead of the parcel data because that is the data type available on the Clay County website. The GIS data provides descriptions of each building that is built within Clay County. Based on the building descriptions, the author of this paper is able to highlight all the buildings that that are more likely to attract heavier traffic and agricultural buildings.

The map shown in Part 1: Step 3 (Figure 9) shows that there are a number of aggregate pits and commercial aggregate sources on the eastern side of the county. On the west side of the county the only aggregate sources are six aggregate pits. The aggregate sources are within 20 miles of County road 95.

The map shown in Part 2: Step 1 (Figure 9) illustrates that the majority of the unpaved roads with AADT values between 200 and 500 are in the western and central areas of the county. There is one road with 230 AADT that is on the east side of the county.

Comparison between Becker and Clay County models

There are four roads in Becker County that fulfill every criteria, with the exception of one. Becker County officials have built LSTs on three of these four roads. This shows that the model can facilitate the county engineers towards selecting candidate roads for an LST but the model cannot definitively confirm that a road is a candidate road.

In Clay County, there is one road that fulfills all the criteria outlined in each step of the computer aided model. The road is Co 72 between 110th street and 120th street and is located east of Moorhead, MN. The rest of the roads selected by the model tend to fulfill either two or three out of the four criteria. Only one LST has been applied in Clay County and this road fulfills three out of the four criteria. According to the literature review, silty clay loam soil is suitable for LSTs but the Clay County officials mention that that they did not have success applying LSTs.

The main difference between the two models is that one set of data can be used to better predict whether heavy traffic will travel on a road. The data available for Becker County provides descriptions of the parcels throughout the county whereas Clay County has building data available on their website. The advantage of using parcel data is it provides a better visual indication on a map so it is easier to see which roads are located within a high density of parcels with an agricultural description. The building data for Clay County provided descriptions of the use of each building. For example, within Clay County there were buildings that were identified as “bins” or “fruit farms”. However, the parcel data from Becker County will describe the same building as agricultural/commercial. This level of detail will add more accuracy to the model and make it more reliable.

State Level Model

Table 5: Documented county roads with Light Surface Treatments in Minnesota

Counties	County Road Name	Light Surface Treatment	Soil Type(Additional Strength)	ADT(Traffic Type)	Road failures
Becker	CO. 120	Otta Seal	Sandy/Sandy Loam(4"-6" of Class 5 with Base stabilizer	230	Minimal
Big Stone	N/A	Otta Seal	N/A	N/A	N/A
Cass	CSAH 25	Otta Seal	Sandy(4-5" of graded aggregate with CaCl)	145(Residential and Agricultural	Minor Potholes
Clay	CO. 95	Otta Seal	Clay Soils	Heavy Agricultural traffic	
Goodhue	CR. 58	Otta Seal	N/A	N/A	Good condition
Houston	N/A	Chip Seal	Silty Clay	60(Mainly Agricultural)	Few thermal cracking no rutting
Itasca	CSAH 51	Otta Seal	Natural Soils (4"-6" of Class 5)	50-150 (Rural/Timber Hauling	Minimal- Requires overlay(10 years later)
Kandiyohi	CR 106 and CSAH 1	Otta Seal and Chip Seal	N/A	N/A	N/A
Olmsted County	CR58	Otta Seal	N/A	N/A	N/A
Otter Tail	T. H. 59	Otta Seal	N/A	N/A	N/A
Saint Louis	CR 274	Otta Seal	Graded Sand and Gravel	260(Rec. and Logging)	Potholes and wash boarding problems
Stevens	Township road	Otta Seal	N/A	N/A	N/A
Wabasha	CO. 73	Otta Seal	Poor sub-base/grade soils(compacted 2" aggregate base)	580(Residential and some Agricultural)	Minimal- patching required

Table 5 continued

Washington (Stillwater Township)	90 St. N.	Otta Seal	N/A	N/A	Several small patching
Winona (Whitewater State Park)	CO. 20	Otta Seal	N/A	N/A	Fair condition but damaged by flooding
Wright	N/A	Otta Seal	N/A	N/A	N/A

Table 5 shows a list of counties located in Minnesota that have applied LSTs on aggregate-surfaced roads and Figure 15 shows these counties on a map. LSTs have been applied in the south-east, north-west and north-east regions of the state of Minnesota. Throughout the interviews with the county officials, some mentioned that counties are more likely to try LSTs on aggregate-surfaced roads if neighboring counties have tried it successfully. The county officials tend to share experiences and equipment so that their peers are also successful. This human factor does influence which counties implement LSTs. According to the interviews, the most important factor to determine if a county should consider LSTs is the soil types found in the county. Sandy loam, loamy sand and silty clay loam soil types have all been shown to successfully support light surface treatments. The maps shown in Figure 15 and Figure 16 support the information found in the literature review. These figures show that LSTs have been applied in regions that predominantly have silty clay loam, sandy loam and loamy sand. However, there are counties such as Big Stone, Saint Louis and Itasca that are exceptions since they are located in regions that do not predominantly have these soil types.

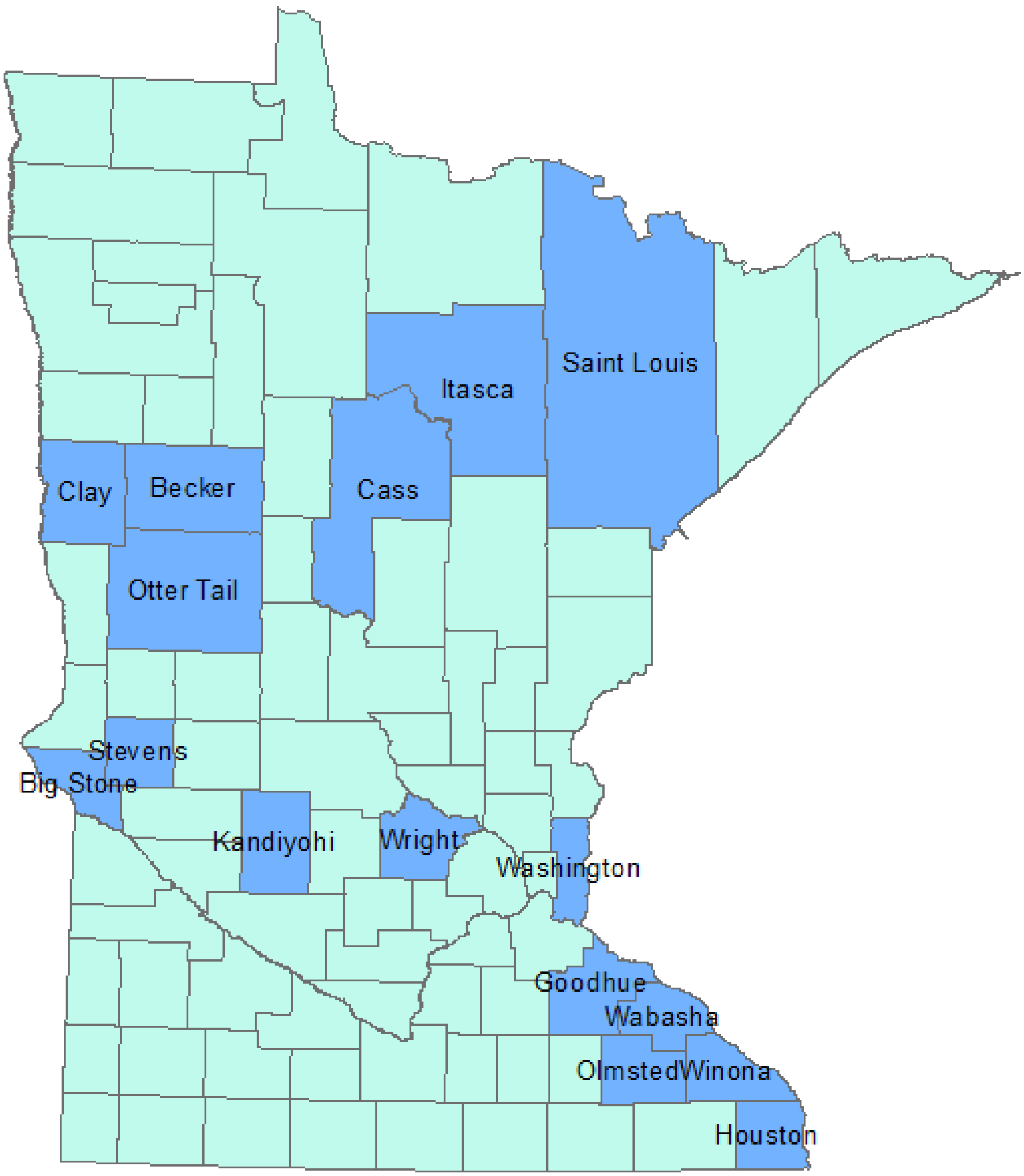


Figure 15: Map of Minnesota showing all counties to apply LST

There is no data available for the Otta Seal applied in Big Stone County, but an Otta Seal was applied in Itasca County and officials found that the cost of construction for an Otta Seal is equal to the cost of applying magnesium chloride and maintenance on the unbound road. As a result, their point of view is that the LST is not a success or a failure. Itasca County found that the costs to apply the Otta Seal increased noticeably because the county decided to treat the sub grade with BASE ONE® along with adding 4 to 6 inches of Class 5 aggregate for the base. Saint Louis did not have success with an Otta Seal but this was due to the workmanship issues. There was an inconsistent application of the aggregate on the road which resulted in the emulsion not being completely covered by the aggregate. This led to corrugations and potholes on the road.

Figure 16 shows that Kandiyohi and Big Stone are the only county amongst sixteen counties that have used LSTs in Minnesota that are located in areas with a majority of unacceptable aggregates. There is a high percentage of unacceptable aggregates in the south-west region of the state and there are no counties in that location that have applied LSTs. According to (Overby & Pinard, 2007), some aggregate types that have been successfully used to build an Otta Seal are Good (Sandstone), Marginal (Gabbro and Granite) and Variable (Basalt and Moraine) aggregates. Good (Greywacke, Sand stone), Marginal (Granite, Quartzite) and Variable (Limestone) are the aggregates used in North America that are considered within the map shown in Figure 17(Gransberg & James, 2005) .

Figure 18 shows the unpaved county roads within the state of Minnesota. Roads with AADT values between 200 and 500 are the roads with suitable traffic levels for an LST. These roads are spread throughout the state but there are a high number of these roads along the east coast of the state of Minnesota. There is a low volume of these roads in the South-West and North-West areas of the state.

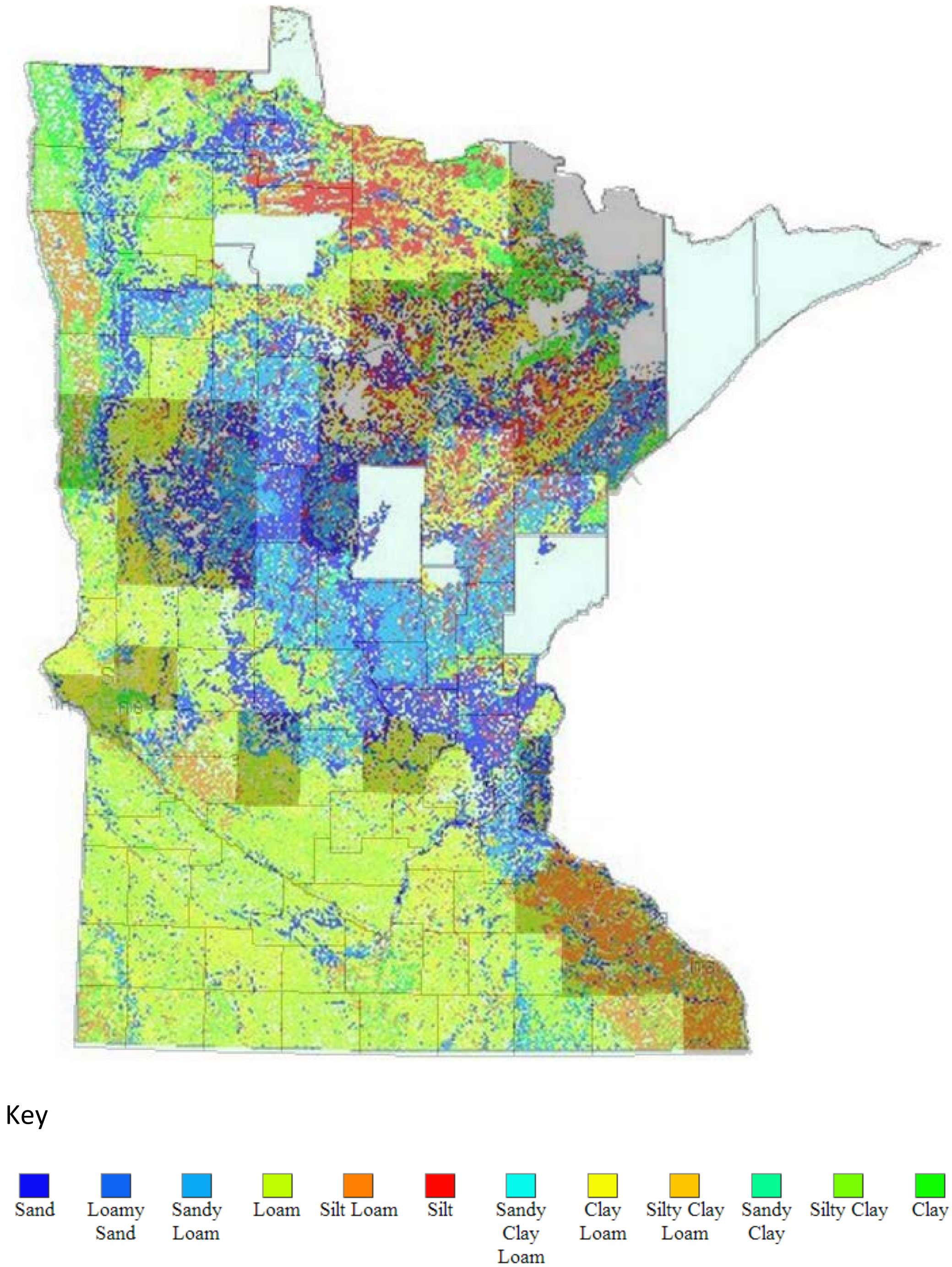


Figure 16: Map of soil types in Minnesota (iAIMS Soil Data-Depth> 20")

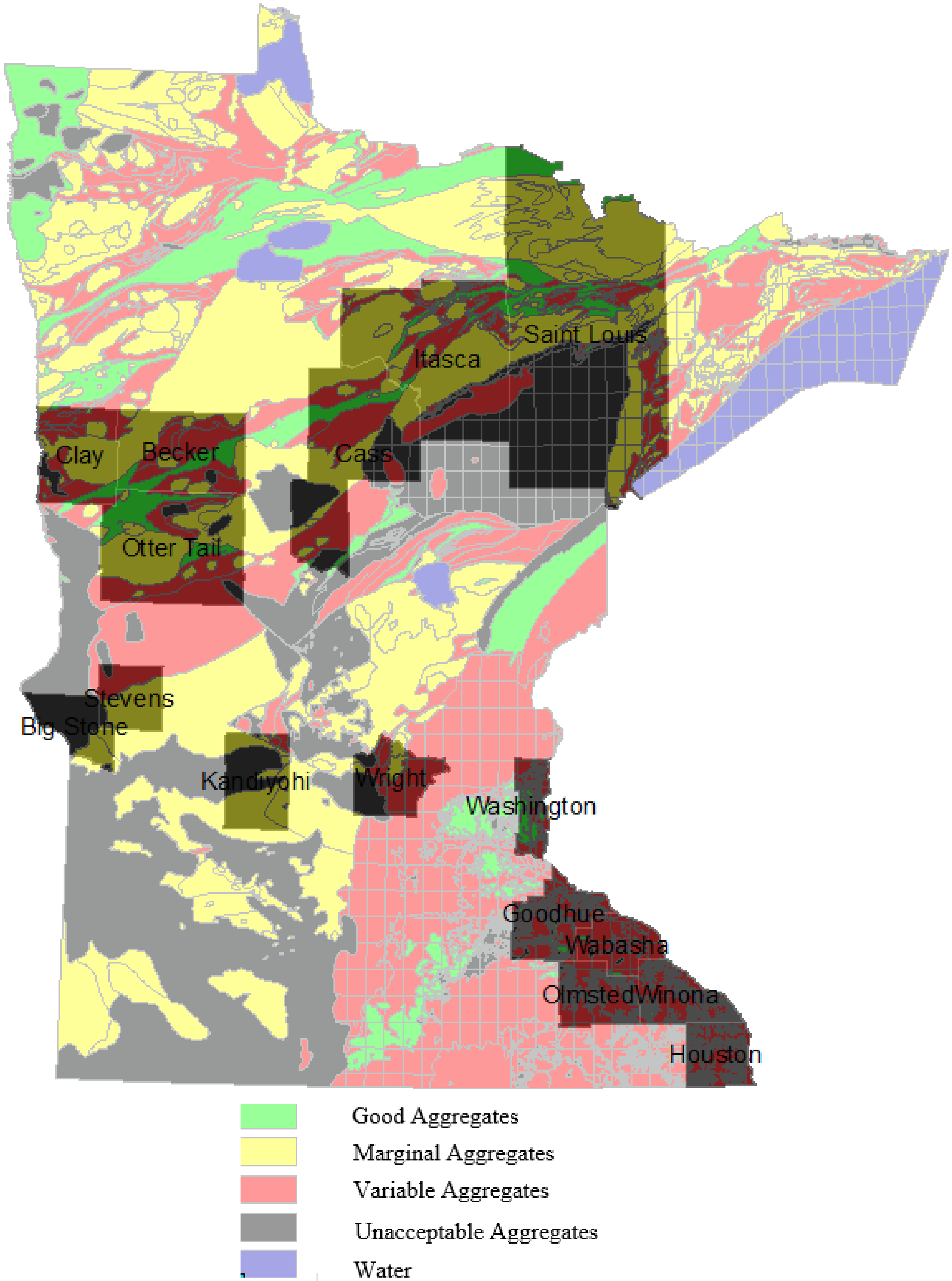


Figure 17: Types of aggregate sources found in the state of Minnesota (Gransberg N. , 2012)

Figure 17 continued

Good Aggregates PSV AVG>55 MIN>45	Known PSV	Greywacke, Sandstone, Arkose, Amphibolite, Banded Gneiss
	Unknown PSV	Arenite = Greywacke/ Sandstone, Wacke = Graywacke
Marginal Aggregates PSV AVG<55 PSV MIN>45	Known PSV	Eclogite, Granitic Gneiss, Gneiss, Mylonite, Quartzite, Hornfels, Larvikite, Hyperite, Monzonite, Trondhjemite, Diorite, Granite, Mangerite, Gabbro, Rhyolite, Greenstone, Romb Porphyry
	Unknown PSV	Andesite = Diorite, Quartz Latite = Quartz Monzonite, Biotite Gneiss = Granitic Gneiss, Felsic Gneiss = Granitic Gneiss, Paragneiss = Gneiss, Quartz Monzonite = Granite/Monzonite, Dacite = Andesite/Rhyolite, Trachyandesite = Andesite, Peridotite = Eclogite, Quartz Diorite = Diorite, Tonalite = Trondhjemite, Alkali Rhyolite = Rhyolite, Quartz Monzodiorite = Diorite, Rhyodacite = Rhyolite, Alkali Granite (Alaskite) = Granite, Migmatite = Eclogite, Orthogneiss = Gneiss, Latite = Rhomb Porphyry, Lamprohpyre ≈Latite = Rhomb Porphyry, Greenschist = Greenstone, Quartz Monzonite = Monzonite, Orthoquartzite = Quartzite, Monzodiorite = Diorite, Quartz Latite = Rhomb Porphyry, Mafic Gneiss = Gneiss, Charnockite = Granite, Phyllonite = Mylonite, Pegmatite = Granite/Rhyolite, Aplite = Granite/Rhyolite, Troctolite = Gabbro
Variable Aggregates PSV AVG<55 PSV MIN<45	Known PSV	Limestone, Augen Gneiss, Marble, Norite, Anorthosite, Syenite, Granodiorite, Basalt, Porphyry
	Unknown PSV	Alluvium, Colluvium,Conglomerate, Diabase = Basalt, Clastics, Glacial Drift/Till/Outwash, Gravel, Volcanic Rock, Plutonic Rock, Granitoid, Trachyte = Syenite, Alluvial Fan, Landslide Deposits, Moraine, Terrace Deposits, Lava Flows, Pyroclastic Rock, Metavolcanic Rock, Metasedimentary Rock, Tectonite, Gabbroid, Alkalic Intrusive = Syenite, Metamorphic Rock Metaconglomerate, Peraluminous Granite, Tholeiite = Basalt, Metaconglomerate, Phonolite = Syenite, Rhyodacite = Granodiorite, Dunite, Quartz Syenite = Syenite, Intrusive Rock, Pyroxenite, Alkali Syenite = Syenite, Breccia, Granofels, Meta-Basalt, Calcerenite = Limestone, Meta-Rhyolite, Tephrite, Trachybasalt, Alkaline Basalt = Basalt, Schist, Dolostone, Mafic/Ultramafic Rock, Granulite, Nepheline
Unacceptable Aggregates	No PSV Data	Sedimentary, Igneous, and Metamorphic Rocks that are unusable for use as wear course aggregates Ex: Noralite, Siltstone, Marl, Lamproite, Mudstone, Shale, Claystone, Evaporite, Argillite, Phyllite, Serpentine, Slate, Blueschist, Mica Schist, etc.

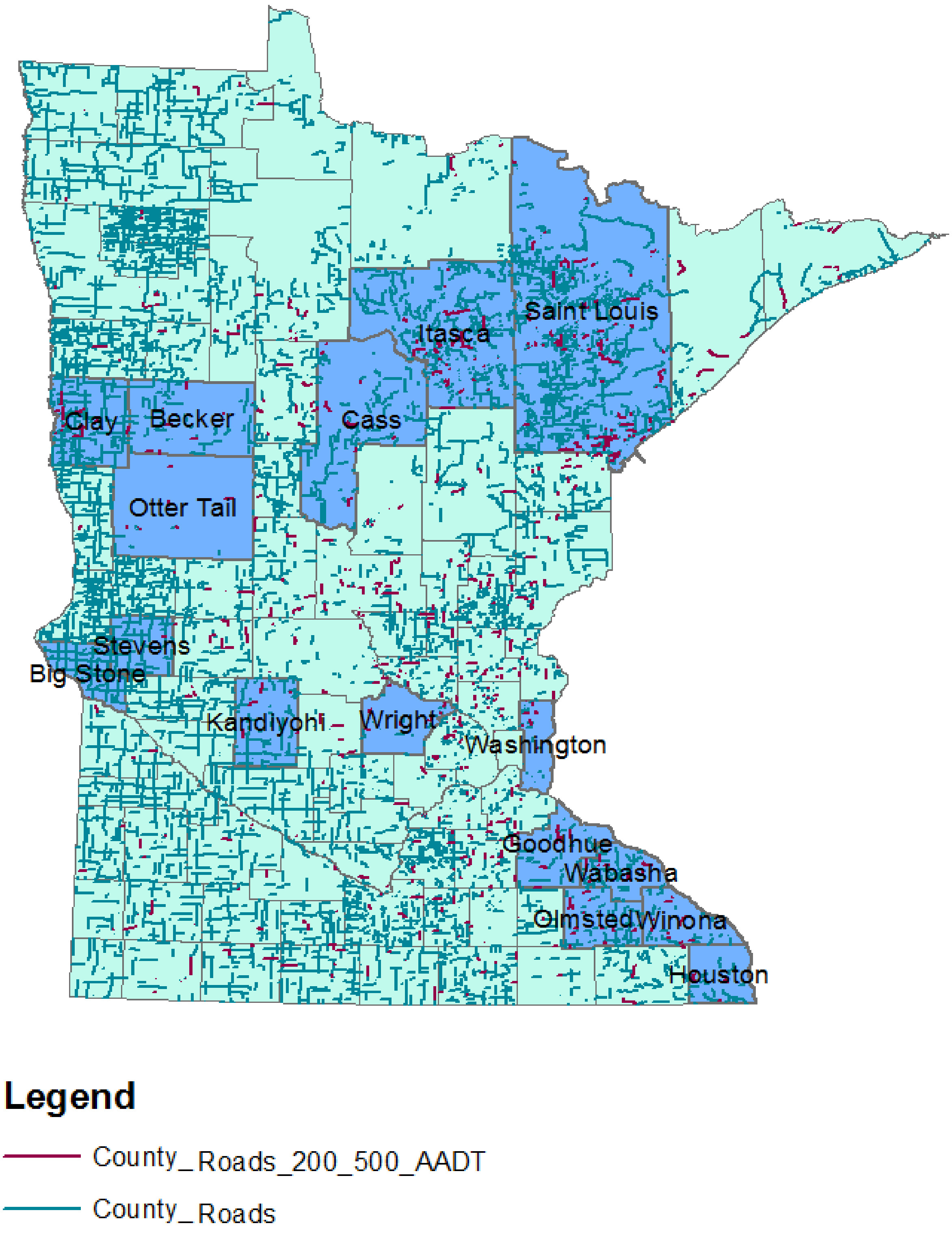


Figure 18: Map showing all unpaved roads in Minnesota

GIS Data available in counties that participated in research survey

Table 6: GIS Data in Minnesota counties that participated in Survey

	County	Shapefiles or GIS Interactive Map	Soil Data	Agricultural Parcels/Buildings	Available Data if Soil or Ag. data is not available
1	Aitkin	Free GIS Interactive Map Fee for Shapefiles	Not available	Not available	Zoning
2	Becker	Free GIS Interactive Map and free Shapefiles	Available	Parcels	N/A
3	Beltrami	Free GIS Interactive Map Fee for Shapefiles	Available	Available in interactive map	N/A
4	Blue Earth	Fee for paper maps	Not available	Not available	County Assessor(Ag Building Search)
5	Cass	Free GIS Interactive Map and free Shapefiles	Not available	Parcels in interactive map	
6	Clay	Free GIS Interactive Map and free Shapefiles	Available	Buildings and Addresses	N/A
7	Cook	Free GIS Interactive Map No shapefiles	Not available	Not available	N/A
8	Dodge	Free GIS Interactive Map Fee for shapefiles	Not available	Parcels in interactive map	County Assessor(Ag Building Search)
9	Freeborn	Free GIS Interactive Map Fee for shapefiles	Not available	Parcels in interactive map	County Assessor(Ag Building Search)
10	Itasca	Free GIS Interactive Map	Not available	Parcels in interactive map	Zoning
11	Hennepin	Free GIS Interactive Map	Not available	Parcels in interactive map	
12	Jackson	Fee for shapefiles	N/A	N/A	

Table 6 continued

13	Kandiyohi	Free GIS Interactive Map	Not available	Parcels and Addresses in interactive map	
14	Lake	N/A	Not available	N/A	
15	Marshall	N/A	Not available	Parcel	County Assessor
16	Morrison	Online Map Fee for shapefiles	Not available	Parcel and Addresses in interactive map	
17	Nobles	N/A	Not available	Not available	County Assessor
18	Olmsted	Free GIS Interactive Map	Not available	Parcel in interactive map	
19	Pennington	N/A	Not available	Not available	County Assessor
20	Pipestone	Free GIS Interactive Map	Not available	Free GIS Interactive Map	
21	Polk	Free GIS Interactive Map Fee for shapefiles	Not available	Parcel and Address points in Interactive Map	
22	Ramsey	Free GIS Interactive Map Fee for shapefiles	Not available	Land Use(Parcels) in interactive map	
23	Redwood	Fee for shapefiles	Not available	Not available	
24	Rice	Free GIS Interactive Map	Available in interactive map	Address points and Parcels available in interactive map	
25	Rock	Fee for shapefiles	Not available	Not available	County Assessor-Tax parcel Information
26	Roseau	Free GIS Interactive Map	Available in interactive map	Parcels and Land Use available in interactive map	

Table 6 continued

27	Saint Louis	8 shapefiles are free(incl. boundaries and lakes) Remaining shapefiles must be requested Free interactive mapping	Not available	Zoning shapefile available for (free) Parcel and information is available on interactive mapping	
28	Scott	Free GIS Interactive Map	Available in interactive map	Parcels available in interactive map	
29	Sherburne	Standard PDF Maps	Available for fee	Parcels available for fee	
30	Sibley	N/A	Not available	Parcel	County Assessor
31	Stevens	Free starter interactive mapping	Available in interactive map	Not available	County Assessor
32	Wabasha	Fee for shapefiles	Not available	Not available	
33	Wadena	Free GIS interactive	Not available	Land Use, Zoning and Parcel data available in interactive mapping	
34	Watonwan	N/A	Not available	Not available	County Assessor
35	Wilkin	Free interactive map Fee for shapefiles	Soil available in interactive mapping	Parcels available in GIS interactive mapping	
36	Winona	Fee for shapefiles	Soil available in interactive mapping	Parcels available in GIS interactive mapping	

Table 6 shows that 64 percent of the counties that participated in the survey have access to the data required to build the computer-aided model. These counties either have access to the requisite data on their websites, on an internal database, or know which office to contact to obtain the information.

Twenty three out of thirty six counties provide an interactive GIS map that is freely accessible on their county websites. The interactive GIS maps allow the user to benefit from the functions of ARCGIS through a user-friendly internet application. It allows the user to perform basic ARCGIS commands to view and obtain information. The information is typically displayed in layers which can be turned on and off to better illustrate the data. The information made available by each county varies. If a layer is made available through the GIS interactive mapping, the county must have access to the layer as a shapefile or in another format that can be imported to ARCGIS. The soil and parcel/address data are required when building the computer aided model. Seven out of the twenty three counties that have the GIS interactive map provide both soil data and parcel/address data. Twenty out of the twenty three counties do have access to the parcel/address data for their respective county. The author found that the soil data can be obtained alternatively through sources other than the county website. Examples of these sources are the Natural Resources Conservation Service (NRCS) and the Minnesota Geospatial Information Office (MNGeo). The rest of the data required for the computer aided model can be obtained from the MN/DOT website, the county websites and through the Office of Materials & Road Research.

Henning's Model compared to the hybrid model

There are seven case study roads within Becker County and Clay County that have been surfaced with an LST (Table 3). The Henning model and the model developed throughout the research investigation will be applied to these case studies to compare the predictions of the models to the results in the field. According to Henning's model, five out of the seven roads would be good candidates for an LST and the remaining roads would not be good candidates

(APPENDIX L USING HENNINGS MODEL TO DETERMINE IF CASE STUDY ROADS ARE CANDIDATE ROADS. The field visits and the interviews showed that Henning's model correctly predicted the success and failure of three out of the seven case study roads. The model developed through this research was able to use the GIS software to correctly identify one road that would not be a candidate road based on the sub grade conditions and the likelihood of heavy truck traffic to travel on that road. The success or failure of the remaining roads is correctly predicted through the decision process that would take place during a site visit (APPENDIX K USING GIS MODEL AND SITE INVESTIGATION TO DETERMINE WHETHER THE CASE STUDY ROADS ARE CANDIDATE ROADS FOR AN LST).

Both models consider the sub grade conditions, the traffic volume and traffic type and the availability of quality aggregate (Table 7). The remaining factors considered in each model are different; mainly due to the fact that Henning's model was established to be applied in developing countries.

Table 7: Comparison between the factors considered in Henning's model and the hybrid model

Henning’s method(Site Visit)	Dayamba and Jahren method(GIS model and/or Site Visit)
Topography	Maintenance costs on aggregate-surfaced roads(Site Visit)
Climate and Soil conditions	Soil support system(GIS and Site Visit)
Non-motorized traffic demand	Roads near buildings/parcels likely to attract heavy traffic(GIS)
Motorized traffic volume	AADT between 200 and 500(GIS)
Impact of dust forming	Demand for an upgrade from an aggregate-surfaced road(Site Visit)
Community impact	
Will traffic increase after sealing	User road safety(Site Visit)
Availability of quality material	Availability of quality material(GIS)

Conclusion

Summary

There are a number of county engineers within the state of Minnesota that successfully built light surface treatments on aggregate-surfaced roads. Throughout the case study research, interviews, surveys, and the literature review all of the county engineers mentioned that one of the most important factors towards building an LST is selecting a good candidate road. When selecting a good candidate road the most important factors highlighted in the research were (parenthetical comments on whether the factor can be explored using a GIS model or a site visit):

- The costs of applying an LST in comparison with the maintenance costs of an aggregate-surfaced road(Site Visit)
- Soil Support System(GIS model and Site Visit)
- Roads near buildings/parcels likely to attract heavy traffic(GIS)
- Traffic amount-Levels between 200 and 500(GIS)
- Demand for an upgrade from an aggregate-surfaced road(Site Visit)
- User road safety(Site Visit)
- Availability of quality material(GIS)

The county model that was developed as part of this investigation identifies areas and roads in Becker and Clay County that would possibly be appropriate for an LST. When the model was validated with the county officials, the model did correctly identify areas where the county officials confirmed that they would consider LSTs.

In Becker County, one road was located in an area highlighted by the model as inappropriate for a light surface treatment. Schurman Drive failed due to a poor soil support system and heavy traffic loads. The remaining roads built using an LST are located in areas that the model shows are appropriate for an LST. Three of the roads built using an LST were highlighted in the model as appropriate candidate roads. The other roads built using an LST were not highlighted in the model but the characteristics of these roads fit the criteria described in the various steps used to develop the model. They were not highlighted in the model because the data for these roads were not included in the ARCGIS files. These roads include township roads that the county crews built. This shows that the unpaved road data is incomplete and that directly affected the results generated by the model.

In Clay County, County Road 95 failed due to the soil conditions and heavy traffic. County road 95 fit three out of the four criteria outlined in the county level step. According to the ARCGIS file, the sub grade beneath the road can be classified as silty clay loam. The county official suggested that the silty clay loam soils are not appropriate for an LST. However, information from the literature review and the state-level model suggest that the silty clay loam would be appropriate for an LST. The author recommends conducting a site visit if the soils beneath a candidate road are silty clay loam. Within the GIS model, CO 95 satisfied three out of the four criteria outlined in the county level model. This would suggest that the road would be a good candidate for an LST. However, the soil conditions were worse than the GIS model portrayed and the GIS model does not account for the percentage of heavy traffic. Both the soil conditions and the percentage of heavy traffic are factors considered on the site visit.

The state-level model confirmed that a number of the counties that successfully applied light surface treatments are located in areas highlighted by the model as an appropriate area. However, there are some exceptions where counties are located in areas that are not highlighted within the model. This discrepancy exists because of the lack of precision of the state level data and because some counties tried LSTs in areas that predominantly have clay, loam or sand soils. Counties such as Clay, Itasca and Saint Louis applied LSTs in areas that are identified as areas that would be difficult to build an LST. These counties experienced difficulties implementing LSTs for multiple reasons. One of the reasons is the conditions found in their county are not favorable for LSTs.

Both models successfully identified areas or roads where LSTs can be implemented under an economically feasible budget. Once these areas are identified, a site visit should be conducted to complete the decision process on whether to use a light surface treatment or an alternative option. These GIS models can be used by local officials as a preliminary assessment in the decision process of choosing an LST but further investigations must be conducted to make a final decision on how to treat the aggregate-surfaced road. In order to validate the model, the model was compared to a decision guide established by Henning (Henning, Bennett, & Kadar, 2007) and the results produced by the model were analyzed by county engineers that have implemented LSTs in Minnesota. Henning's model appeared to be more applicable to roads located in developing countries.

The GIS models are dependent on the availability of the appropriate GIS data. Approximately 20 percent of the counties that responded to the survey have the data needed to implement the GIS models. The research team also found that there are a number of states that have the requisite data to build a GIS model on a state level (Table 8).

Table 8: Examples of states with the requisite GIS data available online

	Step 1				Step 2
States	Soil Type	Land Use/Agricultural Data	Elevation Data	Gravel Sources	AADT of Unpaved Roads
New York	Available per county in NYSGIS Clearinghouse website or USDA Natural Resources Conservation Service website	Available per county in Cornell University Library	Available per county on the NYSGIS Clearinghouse website	Available per region on NYSDOT website	Not Availabl e in state website
Maine	USDA Natural Resources Conservation Service website	Available per town in Maine Geolibrary Geoportal	Available for state in Maine Office of GIS website	Not available on DOT website	Not Availabl e in state website
North Carolina	Available per county in NCSU Libraries	Available per county in NCSU Libraries	Available per county in NCSU Libraries	Not available on DOT website	Not Availabl e in state website
Minnesota	Available per county on county website	Available per county on county website and statewide available on American Farmland Trust website	Available per county on county website	Available for the state on MN/DOT website	Not Availabl e in state website
Michigan	Available per county and/or for the state on the Michigan Department of Technology, management and Budget website	Available per region and/or county on the Michigan Department of Technology, management and Budget website	Available for the state on the Michigan Department of Technology, management and Budget website	Not available on DOT website	Not available on DOT website

California	Available countrywide, statewide and by county by contacting a local NRCS office(USDA)	Statewide available by California Department of Forestry and Fire protection	Available statewide on the California Department of Transportation /GIS Data Library website	Not available on DOT website	Not available on DOT website
Washington State	Available statewide and by county on the Washington State department of Natural Resources website	Available by county on the Department of Ecology website		Not available on DOT website	Not available on DOT website
Alabama	Available per county and/or state from the Alabama Water Quality	Available per county from the Auburn University Alabama View	Available per county from the Alabama Water Quality	Not available on DOT website	Not available on DOT website
Louisiana	Available per county USDA Natural Resources Conservation Service website	Available for the state on the Louisiana Map website	Available for the state on the Louisiana Map website	Not available on DOT website	Not available on DOT website

Benefits of Model

The ARCGIS software gives the user the capability to store data while relating this data to a map. Once the user establishes which roads are good candidates for a light surface treatment, ARCGIS can be used as a tool to determine when to build the light surface treatments. Factors such as high maintenance costs or neighboring property who want the road to be improved can be mapped in the model. These factors can help officials to select which roads should be improved with an LST in the near term and when others should be improved within a typical five year planning period. ARCGIS can also be used to develop a preservation management system so agencies can track the condition of their roads. As a result, local road agencies would be able to make adjustments in their designs or construction practices to prevent the effects of the factors highlighted in the GIS software. The GIS software can be used to show the factors that would influence the success of an application of an LST in a particular area.

Limitations and Recommendations

The main limitation to both the state-level and county-level model is the results that these models yield depend on the precision of the available data. The soil data can be assumed to remain constant, the parcel data and the aggregate source data will be updated relatively frequently but the AADT for the unpaved roads will not be updated as often. As a result, the author recommends conducting road counts to determine the daily traffic count and percentage of truck traffic before applying a light surface treatment. If it is not possible to conduct a road count, there are some counties in Minnesota that design the road bases of an LST assuming 10-12 percent of the total traffic will be truck traffic. Another limitation is the model will be difficult to implement for agencies that do not currently use computer software to manage their road network. If that is the case, the county could still use the site investigation decision tools provided by the research project to determine whether or not to apply an LST on a particular road.

Future Research

In order to extend this research, GIS computer aided models can be created for a larger sample size of counties. A higher number of counties would allow the research team to make more conclusive statements about the factors that affect the success of LSTs. A study can be conducted to rank these factors based on which factor has the most effect on the success of an LST.

Another area of interest would be to use a GIS model to select which treatment method is most appropriate for candidate aggregate-surfaced roads. The treatments that can be considered in the study are LSTs, Base Stabilizations Products (BSP), or a combination of both treatments. Factors that could be considered in this model are the slope of the road, the condition of the road, the climate of the area, the location of the aggregate sources and emulsion/product suppliers, the performance of LSTs that are in proximity to the site and the location of experienced contractors who have applied LSTs on aggregate-surfaced roads. This model must also consider other factors such as the cost of applying the LST and the expected performance of the road. A hybrid model might be best suited for this decision because such a model can best accommodate the number of factors that could be considered when making decisions about applying an LSTs.

CHAPTER 3

INVESTIGATION OF GAP ANALYSIS FOR LIGHTLY SURFACED ROAD DESIGN USING CASE STUDY

A paper to be submitted to the Transportation Research Board

Francis O. Dayamba, Charles T. Jahren

Abstract

A growing concern for local road officials is finding an economic solution towards managing damaged paved roads within their road network. One solution would be to perform a stabilized full depth reclamation and apply a light surface treatment (LST) as a surface course. This paper conducts an analysis of three pavement design methods that are used by local road officials to design the road structure of a light surface treatment. The three pavement designs considered in this study are the Minnesota Granular Equivalence (GE) Method, a computerized version of the Mechanistic-Empirical (MnPave) method and the AASHTO method. The two case study roads that are chosen to conduct this study are CSAH 14 in Becker County, Minnesota and CSAH 10 in Goodhue County, Minnesota. Both roads are located in rural areas and have traffic volumes of 450 AADT and 1200 AADT respectively. This paper outlines step-by-step processes for each road design method and highlights the limitations that exist when using these pavement design methods to design the road structure of an LST. Additionally, this research provides recommendations to address these limitations. This paper concludes that there is a demand for a design method that is straightforward to implement, but considers a number of factors such as the existing road layers, the climate, a wide range of material selection, the cost

and constructability of implementing an LST, and highlights traffic levels that are likely for low-volume roads.

Introduction

Local road officials in the United States are often faced with the responsibility of maintaining road networks under a limited budget. As a result, they are considering alternative methods for rebuilding damaged paved roads. One such method of treating a damaged paved road would be to construct a stabilized full depth reclamation (SFDR) and apply a light surface treatment (LST) as a surface course. The SFDR can be used to correct all surface distresses and base deficiencies (Johnson & Jackson, 2006). The light surface provides a durable, impervious surfacing that increases the skid resistance and reduces the amount of gravel loss and dust on a gravel road (Overby & Pinard, 2013). Light surfaces add little to no structural strength to a road but by preventing the ingress of water, they enable the strength of the sub-base or pavement to be preserved (Greening, Gourley, & Tournee, 2001). As a result, it is particularly important to design the road structure to have sufficient strength to withstand the traffic loads.

The current practice is for pavement engineers to use pavement design methods to design the road structure of an LST. A survey conducted by (Hall & Bettis, 2000) showed that the local officials in 37 out of the 48 states in the continental United States use the AASHTO method to design Low-Volume Roads (LVR). The local officials in the remaining states use local procedures to design LVRs. Since such pavement design methods were established to design typical pavements that typically include a hot mix asphalt layer with a thickness, there are features within the design methods that do not address the specific conditions found with an LST.

The pavement designs considered in this paper are the Granular Equivalence (GE) Method, the AASHTO method, and a computer application version (MnPave) of the Mechanistic-Empirical method (Minnesota Department of Transportation, 2012). Throughout the study, the 10-Ton Flexible pavement design charts and the Staged 9-ton and 10-ton Bituminous Pavement Design tables (Labuz J. , 2012) will be considered as a means to implement the GE method. The MnPave software will be used to conduct the Mechanistic-Empirical method and a nomograph will be used to implement the AASHTO method. The case study research will be conducted on two paved roads that are located in rural areas in the state of Minnesota.

The GE method has been used by local road officials in Minnesota since 1992 (Hall & Bettis, 2000). Guides for the AASHTO method have been implemented for roads designs since 1962. The most updated AASHTO method guide was published in 1993 and is titled the AASHTO Guide for the Design of Pavement Structures (Johnson A. , 2013). The procedures for using the Mechanistic Empirical (M-E) method were published in 2002 (Shahji, 2006).

The Minnesota Granular Equivalence Method is used to find the General Equivalence (GE) of a pavement design (Labuz J. , 2012). The factors required to use the chart are the cumulative 18 kip ESALs and the R-values (Figure 22). The Flexible Pavement design tables use the Soil Factor and a HCADT value (Figure 19) (MN/DOT, 2007). The AASHTO (American Association of State Highway Transportation Officials) Method is established to determine a weighted structural number (SN) (FHWA, 2013). SN expresses the capacity of pavements to carry loads for a given combination of soil support, estimated traffic, and environment (Labuz J. , 2012). For the purpose of this research, the AASHTO method is defined by seven steps. Each step requires the user to find key parameters towards determining the structural number. The factors used to find the required SN of a particular road are Equivalent Single Axle Loads (ESALs), California Bearing Ratio (CBR) or Soil support Values and the location of the road. The Mechanistic Empirical method is a design method that firstly considers the site and construction conditions and these findings are used to design a trial design (Skok, Timm, Brown, Clyne, & Johnson, 2003). The trial design is then evaluated and if more strength is required in the design, the road is redesigned accordingly. This process is repeated until the design is acceptable.

This paper will show the shortcomings of each design method when they are used to design an LST. Then the authors will suggest how to improve the current design methods so that the design methods are better applicable to roads with LSTs.

Literature Review

The literature review consisted of searching for existing road design methods that were developed to design the road structure of paved roads that will support light surface treatments.

A published guide discusses how to design the road structure of a bituminous surface treatment (or light surface treatment) in tropical or sub-tropical countries (Rolt, Smith, Toole, &

Jones, 1993). Throughout their design, the main factors that are considered are the Traffic ESALs, the sub grade strength (CBR %), and the various layers within the road. There are eight charts that a designer can choose from to develop the road design. Each chart provides a various combination of layers. The road bases included in this design method are Granular, Composite, Bituminous and Cement treated bases. The surfaces included are Surface dressings (light surface treatments), Semi-structural surfaces and Structural surfaces. Most road designs include a granular layer to provide sufficient structure and reduce the failures that appear on the surface.

(Russel & Hitch, 1977) Discuss a pavement design chart and they relate it to the structure of a lightly surfaced road. The pavement design chart considers the Traffic ESALs and the sub grade strength as main factors for the road structure. This design method provides minimum depths for the base and the sub-base but uses a chart to calculate the depth of the sub grade. The chart resembles the pavement design chart used to calculate the Total GE of a pavement design. The differences are that this pavement design chart considers the CBR Values instead of the R-Values for the sub grade soil. Also, this chart provides the designer with a thickness of a sub grade. The Total GE method can be used to determine the total thickness required by the traffic and soil conditions.

Both research papers listed above were developed to be implemented in tropical environments. These methods will be used as a template to determine how to improve the design methods used in the United States.

Methodology

The three pavement design methods that are considered in this study are the Minnesota Granular Equivalence (GE) Method, the Mechanistic-Empirical method and the AASHTO Method. A general assumption with these pavement designs is that the depth of the bound and unbound layers will be equal to the depth of the existing pavement structure including the pavement and any base or sub-base courses. In order to implement these design methods, values for the soil conditions and the heavy traffic ESALS over the life of the road must be selected.

Finding road conditions and properties

Various soil (or sub grade) classifications

The R-Value, the Soil factor, the MN/DOT classification and the AASHTO soil classification are the parameters used in the case study counties to describe the soil conditions. Table 10can serve as a means to convert between these various parameters. The R-value can be calculated using a tool called the Falling Weight Deflectometer (FWD) analysis tool (Figure 21). The FWD tool can be used to determine an average R-Value over the section of the road. If the FWD data is not available or the R-Value of the soil is not documented then Table 10can be used to convert the soil classification into an estimated R-Value. One method that can be used to confirm the R-value is to use the GIS interactive maps to analyze the types of soils found beneath a case study road. These maps are typically available on county websites if the county uses GIS data (Example shown in Figure 35).

Heavy Traffic ESALs

The tool used to calculate the cumulative 20-year ESALs for the case studies is the ESAL calculator made available through the Minnesota Department of Transportation (link to ESAL calculator is below). This ESAL calculator has two formats. The first format uses heavy traffic percentages assigned by MN/DOT that vary depending on the traffic type and volume. The second format allows the user to manually enter the expected heavy commercial traffic. For example, the table below shows the heavy traffic percentages assigned by the ESAL calculator for a road located in a rural area with traffic levels of 751-1500 AADT.

Table 9: Table to show the heavy traffic percentages assigned by MN/DOT for roads with AADT levels of 751-1500 AADT

Heavy Traffic percentages assigned by MN/DOT for a rural road with traffic levels of 751-1500 AADT.	
Vehicle Type	**Vehicle Class (%)**
2AX-6TIRE SU	3.69%
3AX+SU	1.71%
3AX TST	0.33%
4AX TST	0.57%
5AX+TST	2.10%
TR TR, BUSES	1.03%
TWIN TRAILERS	0.02%
Total	**9.45%**

The ESAL values generated through the ESAL calculator are based on average values of varying types of truck traffic, the AADT of the road and the road location (urban/rural). An assumption considered in the ESAL calculator is that traffic levels have not increased since they were last documented.

The ESAL calculator for the state of Minnesota can be accessed through the following link: http://www.dot.state.mn.us/stateaid/esal/ESAL_Calc_11-15-2010.xlsx Accessed September 2013

Bituminous layer within pavement design methods

When the Granular Equivalency method and the Mechanistic-Empirical method are used to produce road designs, they both produce road designs that require a minimum bituminous layer. The Granular Equivalency method requires a 3 in bituminous layer and the mechanistic-empirical method requires a 1 in bituminous layer. The 3 in bituminous layer is neglected when the GE method is used to design the road structure. The 1 in HMA layer in the Mechanistic-Empirical method does add structural value to the road in the MnPave software. However, the author understands that 1" of HMA would not provide structural value to a road. The author recommends methods that can be used to address these mandatory bituminous layers in a following section of this paper.

Minnesota Granular Equivalence Method

Minnesota GE Method-Ultimate 10-ton Staged (9-ton) and 10-ton Flexible Pavement Design Using Soil Factors

Figure 19 and Figure 20are the tables that are used to develop 9-ton and 10-ton flexible pavement designs using soil factors to implement the GE method. This method begins by identifying the amount of daily traffic that travels on the road. The tables for the 9-ton design are all based on the heavy commerical traffic. The 10-ton design tables are also based on the heavy commercial traffic with the exception of roads with AADT values less than 1000. Once the appropriate table is selected and the soil factor is known, the total required GE can be found.

Two simultaneous equations can be established and solved to design an SFDR of an existing road. The first equation would relate to the existing structure of the road and the second equation would relate to the GE values of each road layer. Once these equations are solved, an SFDR depth and an aggregate base depth will be established.

ULTIMATE 10 TON STAGED FLEXIBLE PAVEMENT DESIGN USING SOIL FACTORS[1,5]

Required Gravel Equivalency (G.E. in inches) for various Soil Factors (S.F.)

For new construction or reconstruction use projected ADT or HCADT; for reconditioning projects use present ADT or HCADT

Designs shown here are for an intital 9 Ton pavement structure. Agencies can add pavement structure to increase to 10 Tons in the future

9 TON Staged : < 150 HCADT			9 TON Staged: 151 to 300 HCADT		
	Minimum	Total		Minimum	Total
S.F.	Bit G.E.	G.E.	S.F.	Bit G.E.	G.E.
50	7	10.3[6]	50	7	14
75	7	13.9	75	7	17.5
100	7	17.5	100	7	21
110	7	19	110	7	22.4
120	7	20.5	120	7	23.8
130	7	22	130	7	25.2

9 TON Staged: 301 to 600 HCADT			9 TON Staged: 601 to 1100 HCADT		
	Minimum	Total		Minimum	Total
S.F.	Bit G.E.	G.E.	S.F.	Bit G.E.	G.E.
50	7	16	50	8	18.5
75	7	20.5	75	8	23.7
100	7	25	100	8	29
110	7	26.8	110	8	31.1
120	7	28.6	120	8	33.2
130	7	30.4	130	8	35.3

9 TON Staged: 1101 to 1500 HCADT[2]		
	Minimum	Total
S.F.	Bit G. E.	G.E.
50	8	20.3
75	8	26.4
100	8	32.5
110	8	35
120	8	37.4
130	8	39.8

TYPE OF MATERIAL[3]	SPECIFICATION	G.E. FACTOR
Bituminous Pavement	2360	2.25
Cold-Inplace Recycling (CIR)	2331	1.5
Rubblized Concrete	2231	1.5
Full Depth Reclamation	2331	1
Aggregate Base class 5 & 6	3138	1
Aggregate Sub-Base class 3 & 4	3138	0.75
Select Granular Mat'l	3149.2B2	0.5

AASHTO SOIL CLASS	SOIL FACTOR (S.F.)	ASSUMED R-VALUE	GENERAL[4] PLASTICITY
A - 1	50 - 75	70 - 75	NP
A - 2	50 - 75	30 - 70	SP
A - 3	50	70	NP
A - 4	100 - 130	20	SP
A-5	130+	na	na
A - 6	100	12	P
A - 7 - 5	120	12	P
A - 7 - 6	130	8	P

Figure 19: 10-ton Staged (9-ton) Flexible Pavement Design Using Soil Factors

10-TON PAVEMENT DESIGN USING SOIL FACTORS

LESS THAN 1000 ADT (200,000 ESALs)					
	Bituminous			Concrete	
Soil Factor	Minimum Bit. G. E.	Total G. E.	*Allowable Defl.*	StreetPave Slab Thick.	Tradition. Slab Thick.
50	6	10	*29*	5.0^{U}	4.5^{U}
75	6	10	*42*	5.0^{U}	4.5^{U}
100	6	16	*49*	5.5^{U}	4.5^{U}
110	6	18	*51*	5.5^{U}	4.5^{U}
120	6	20	*53*	5.5^{U}	4.5^{U}
130	6	23	*60*	5.5^{U}	4.5^{U}

LESS THAN 150 HCADT (400,000 ESALs)					
	Bituminous			Concrete	
Soil Factor	Minimum Bit. G. E.	Total G. E.	*Allowable Defl.*	StreetPave Slab Thick.	Tradition. Slab Thick.
50	7	10.3	*28*	5.0^{U}	4.5^{U}
75	7	13.9	*37*	5.5^{U}	4.5^{U}
100	7	17.5	*46*	6.0	6.0
110	7	19	*49*	6.0	6.0
120	7	21	*51*	6.0	6.0
130	7	23	*60*	6.0	6.0

150 - 250 HCADT (400,000 - 850,000 ESALs)					
	Bituminous			Concrete	
Soil Factor	Minimum Bit. G. E.	Total G. E.	*Allowable Defl.*	StreetPave Slab Thick.	Tradition. Slab Thick.
50	7	14	*25*	6.0	6.0
75	7	17.5	*32*	6.0	6.0
100	7	21	*41*	6.0	6.0
110	7	22.4	*43*	6.0	6.0
120	7	23.8	*46*	6.0	6.0
130	7	25.2	*55*	6.0	6.0

251 - 550 HCADT (850,000 to 2,000,000 ESALs)					
	Bituminous			Concrete	
Soil Factor	Minimum Bit. G. E.	Total G. E.	*Allowable Defl.*	StreetPave Slab Thick.	Tradition. Slab Thick.
50	7	16	*23*	6.0	6.0
75	7	20.5	*29*	6.0	6.0
100	7	25	*35*	6.0	6.0
110	7	26.8	*37*	6.0	6.0
120	7	28.6	*39*	6.0	6.0
130	7	30.4	*45*	6.5	6.0

551 - 1000 HCADT (2,000,000 - 4,000,000 ESALs)					
	Bituminous			Concrete	
Soil Factor	Minimum Bit. G. E.	Total G. E.	*Allowable Defl.*	StreetPave Slab Thick.	Tradition. Slab Thick.
50	8	18.5	*21*	6.5	6.0
75	8	23.7	*25*	6.5	6.5
100	8	29	*30*	7.0	6.5
110	8	31.1	*31*	7.0	6.5
120	8	33.2	*33*	7.0	7.0
130	8	35.3	*38*	7.0	7.0

1001 - 1500 HCADT (4,000,000 - 6,000,000 ESALs)					
	Bituminous			Concrete	
Soil Factor	Minimum Bit. G. E.	Total G. E.	*Allowable Defl.*	StreetPave Slab Thick.	Tradition. Slab Thick.
50	8	20.3	*20*	6.5	6.5
75	8	26.4	*23*	6.5	7.0
100	8	32.5	*27*	7.0	7.5
110	8	35	*27*	7.0	7.5
120	8	37.4	*28*	7.0	7.5
130	8	39.8	*32*	7.5	7.5

Over 1500 HCADT (> 6,000,000 ESAL's)
Use Mechanistic Design

MATERIAL	TYPE OF MATERIAL	G.E. FACTOR
Superpave Hot Mix	Spec. 2360	2.25
Plant Mix Asp Pave	Spec 2360	2.25
Aggregate Base	Class 5 & 6	1
Aggregate Base	Class 3 & 4	0.75
Select Granular	Spec 3149.2B	0.5

AASHTO SOIL CLASS	SOIL FACTOR	ASSUMED R-VALUE	k Value
A - 1	50 - 75	70 - 75	?
A - 2	50 - 75	30 - 70	?
A - 3	50	70	?
A - 4	100 - 130	20	?
A - 5	130 +	--	?
A - 6	100	12	?
A - 7 - 5	120	12	?
A - 7 - 6	130	10	?

Figure 20: 10-ton Flexible Pavement Design Using Soil Factors

Minnesota GE Method-10 ton Bituminous Pavement design Chart

In order to determine the Total GE value for a road using The Bituminous Pavement design chart (Figure 22) it requires the user to select a Cumulative 20-year ESAL value and the sub grade R-Value. In order to begin the design process, the user should draw a perpendicular line from the ESAL axis to intersect the corresponding R-Value. The user should then draw another perpendicular line to intersect the Total required GE axis. The point at which the line intersects the axis determines the total required GE to provide sufficient structural support for the road.

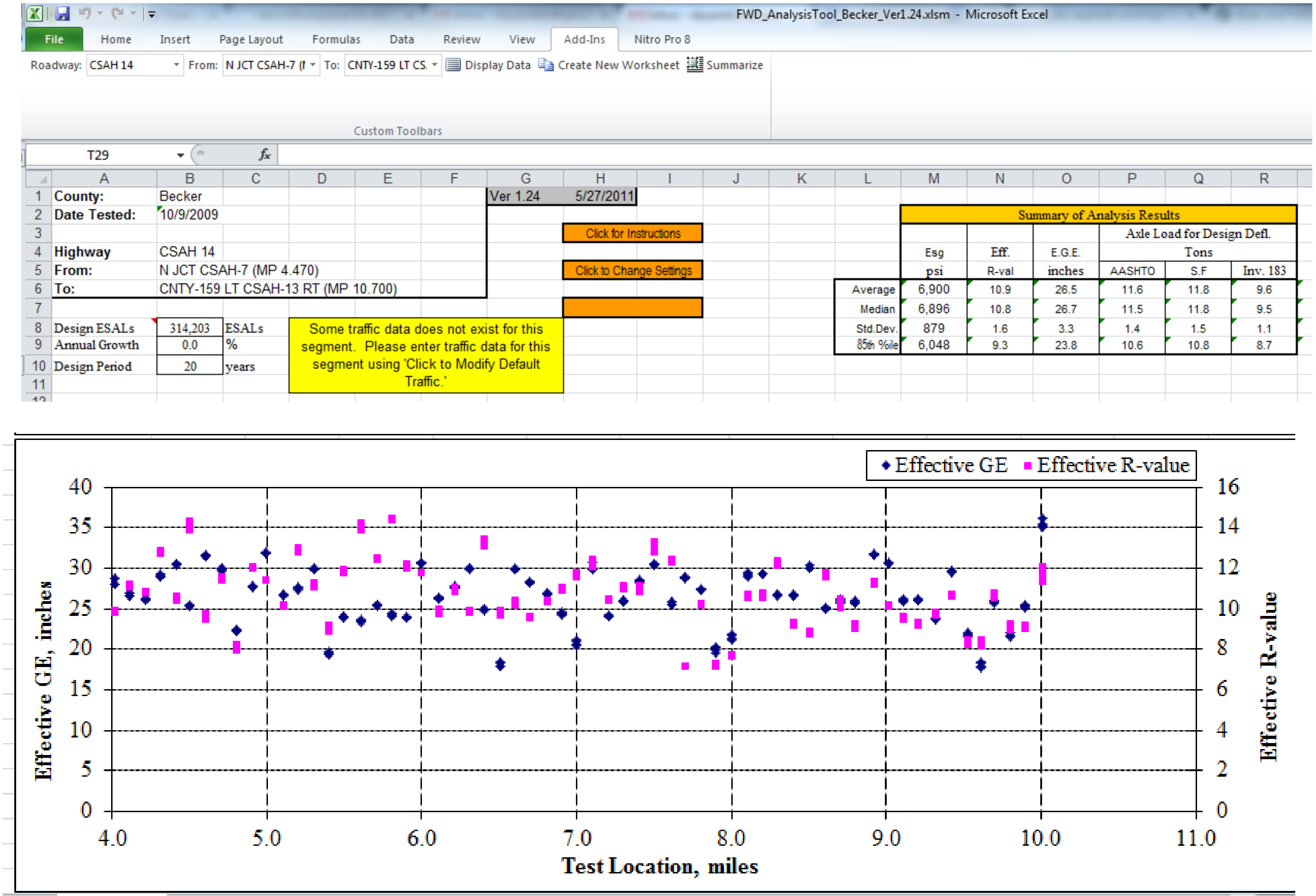


Figure 21: FWD Analysis tool to determine an R-value for the sub grade

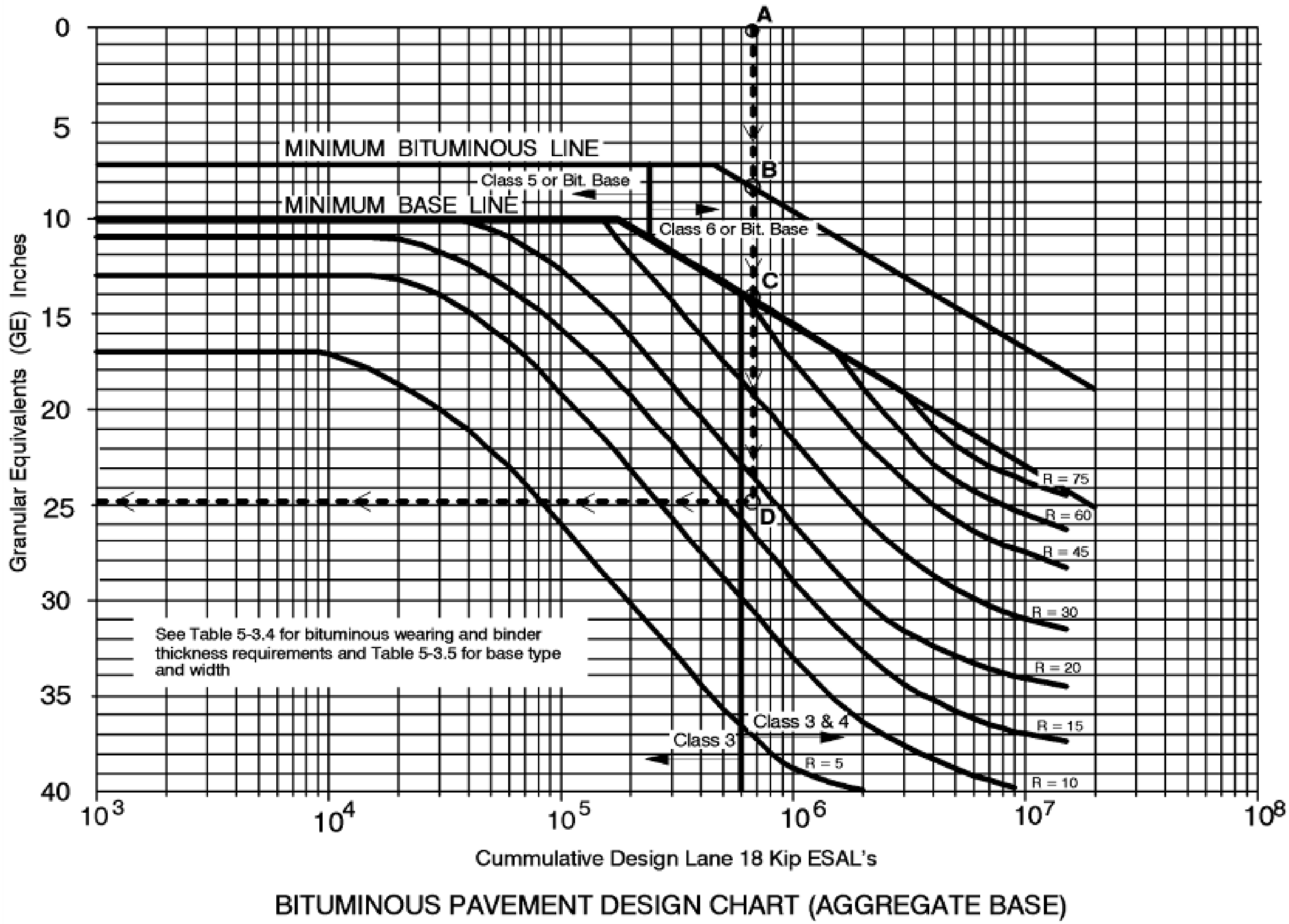


Figure 22: The Bituminous Pavement Design Chart (10 ton)

Table 10: Table to show the relative comparisons of the various soil characteristics (MNLTAP)

Soil Properties								
Mn/DOT Classification	Field Identification	Ribbon (1) Length (in.)	Rating	Possible Equivalent Classes				
				Mn/DOT Soil Factor	AASHTO	ASTM Unified	CBR	R-Value
Gravel (G)	Stones pass 75 mm sieve, retained on 2 mm	0	Excellent	50-75	A-1	GP-GM	-	70 (assumed)
Sand (Sa)	Will form a cast when wet. Crumbles easily, 100% passes 2 mm sieve.	0	Good to Excellent	50-75	A-1, A-3	SP-SM	14.1	70 (assumed)
Loamy Sand (Lsa)	Grains can be felt. Forms a cast when Wet.	0	Good to Excellent	50-75	A-2	SM, SC	7.2	50-70
Sandy Loam (SaL) Slightly plastic (<10% clay)	Slightly plastic. Sand grains seen and felt. Gritty.	0-0.75	Fair to Good	50-75	A-2	SM, SC	4.3	20-60
Sandy Loam (SaL) Plastic (10-20% clay)	Slightly plastic to plastic. Sand grains seen and felt. Gritty.	0.75-1.5	Fair	100-130	A-4	SM, SC	3.9	15-30
Loam (L)	Somewhat gritty, but smoother than SaL.	0.25-1.5	Fair	100-130	A-4	ML, MH	3.6	12-30
Silt Loam (SiL)	Smooth, slippery or velvety. Cloddy when dry. Easily pulverized.	0.0-1.5	Poor	120-130	A-4	ML, MH	3.1	10-40
Sandy Clay Loam (SaCL)	Somewhat gritty. Considerable resistance to ribboning.	1.5-2.5	Fair to Good	100	A-6	SC, SM	3.8	15-30
Clay Loam (CL)	Smooth, shiny, moderate resistance to ribboning.	1.5-2.5	Fair to Good	100	A-6	CL	3.4	10-20
Silty Clay Loam (SiCL)	Dull appearance, slippery. Less resistance to ribboning than CL. Very plastic but gritty. Long, thin ribbon, 0%-30% sand.	1.5-2.5	Poor	120-130	A-6	ML/CL	3.1	10-20
Sandy Clay (SaC)	Very plastic but gritty. Long, thin ribbon, 50-70% sand.	2.5<	Fair	120-130	A-7	SC	-	10-20
Silty Clay (SiC)	Buttery, smooth, slippery. Less resistance to ribboning than CL.	2.5<	Poor	120-130	A-7	ML/CL	3.1	10-20
Clay (C)	Smooth, shiny when smeared, long thin ribbon or thread.	2.5<	Fair	120-130	A-7	CL, CH	3.2	10-20

Mechanistic-Empirical method using a computer software (MnPave)

The MnPave software was developed by MN/DOT to conduct pavement designs. In order to use the software it must be downloaded from the following link. (http://www.dot.state.mn.us/materials/pvmtdesign/software.html)Accessed July 2013

The MnPave guide that serves as a user's manual for the software (Minnesota Department of Transportation, 2012). There are five primary user interface screens within the software. On the Project Information page, the user is asked to enter the basic project information. The Climate page requires the user to identify the location of the road on a map of Minnesota. Based on the road location, the software generates approximate temperatures for the road surface. The ESAL page allows the user to either enter the ESAL value of heavy traffic throughout one year or throughout the road design life. All the designs considered in this study are 20 year designs. The Structure page allows the user to input the road layers and their respective thicknesses. The road structure can be developed using basic, intermediate and advanced settings. Throughout this paper, the information that was gathered through the case study research was sufficient for using the intermediate setting. Once all the information is entered into the software, the Output window then generates the road design. The program displays how many years the road is expected to last in good condition before failing in rutting or in fatigue. The program is also capable of running a Monte Carlo simulation to calculate the probability that the road will fail as the software indicated.

AASHTO Method using nomographs

The AASHTO method uses a nomograph to identify a Structural Number (SN) for the total pavement structure (AASHTO, 1993). This structural number is identified in seven steps. Once the structural number is found, then two simultaneous equations can be developed and the thickness of each layer can be determined.

Step 1: Calculate ESALs

In order to calculate the ESALs, the ESAL calculator provided by MN/DOT will be used (See page describing ESALs).

Step 2 and Step 3: Determine the CBR values of the soil

Select a CBR, % based on the sub grade conditions of the road

Table 11: Typical CBR Values for Various Soils (Rollings and Rollings 1996 in White et al 2000)

Material Description	CBR, %
Thumb penetration into the wet clay soil	
Easy	< 1
Possible	1
Difficult	2
Impossible	3+
A trace of a footprint left by a walking man	1
SC: clayey sand	10-20
CL: lean clays, sandy clays, gravelly clays	5-15
ML: silts, sandy silts	5-15
OL: organic silts, lean organic clays	4-8
CH: fat clays	3-5
MH: plastic silts	4-8
OH: fat organic clays	3-5

Draw a perpendicular line from the CBR % axis to the curve. Proceed to draw a perpendicular line from the curve to the DCP Index axis and determine CBR value.

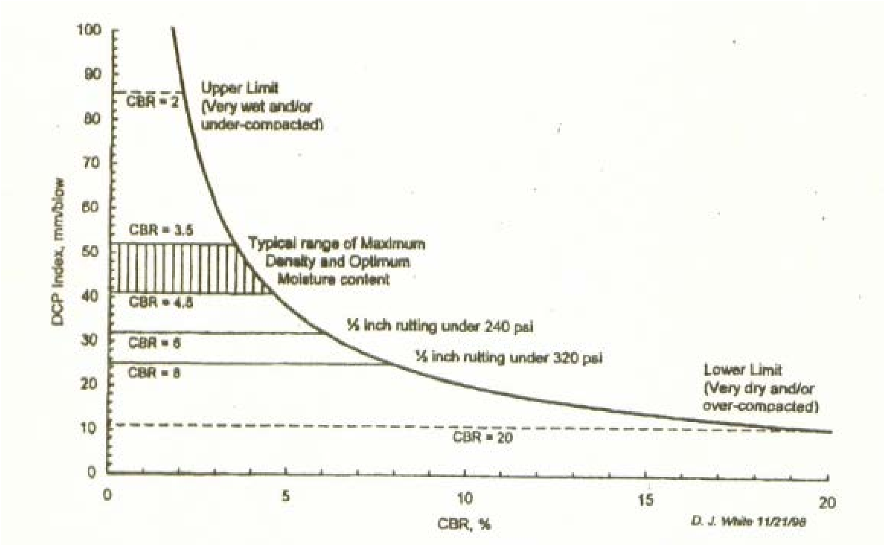


Figure 23: Iowa DOT DCIP Index Guidelines Chart

Step 4: Use the CBR value to find the Soil Support Value.

Draw a perpendicular line from the CBR axis to the Soil Support Value axis.

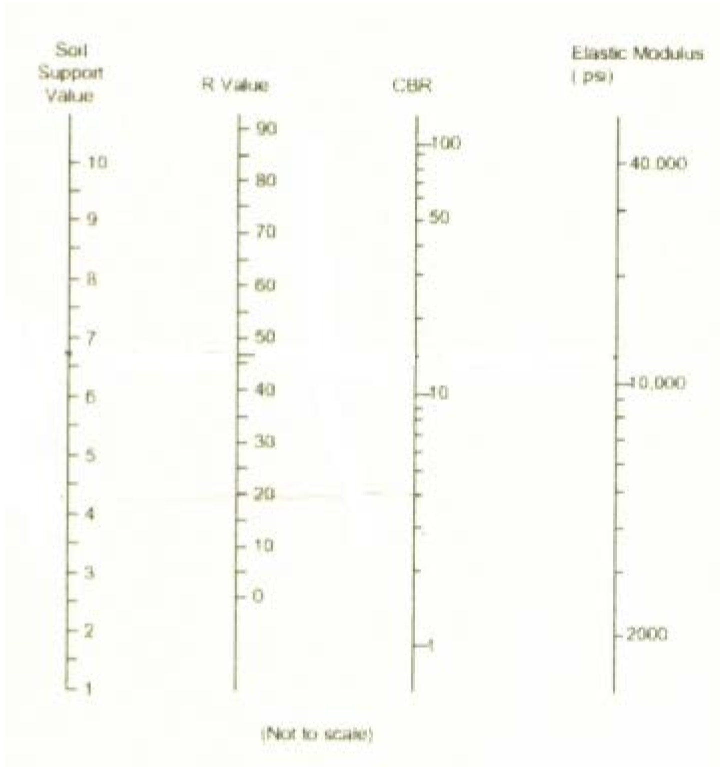


Figure 24: Illustration of how soil support is determined from other test data-Pre-1986 AASHTO Guide

Step 5: Find Structural Coefficients

Step 5 uses a table to identify the structural coefficients for a full depth reclamation (SFDR) layer and an Aggregate base. The coefficients used for the SFDR and Aggregate base are 0.32 and 0.07 respectively. There is no coefficient specifically outlined for an SFDR so a value of 0.32 was selected by the authors based on the values of bituminous-treated graded coarse (0.34) and sand asphalt (0.3). The crushed stone is assumed to have the same structural value as an aggregate base; therefore it was assigned a value of 0.07.

Table 12: Structural Layer Coefficients Proposed Committee on Design (Yoder and Witczak 1975)

Pavement Component	Coefficient[b]
Surface course	
Roadmix (low stability)	0.20
Plantmix (high stability)	0.44[a]
Sand asphalt	0.40
Base course	
Sandy gravel	0.07[c]
Crushed stone	0.14[a]
Cement-treated (no soil-cement)	
Compressive strength @ 7 days	
650 psi or more[d]	0.23[c]
400 psi to 650 psi	0.20
400 psi or less	0.15
Bituminous-treated	
Coarse-graded	0.34[c]
Sand asphalt	0.30
Lime-treated	0.15–0.30
Subbase course	
Sandy gravel	0.11[a]
Sand or sandy clay	0.05–0.10

Step 6: Regional Factor

Identify the location of the road on the map and select a regional factor accordingly.

Figure 25: Contours of Equal Regional Factors- Pre-1986 AASHTO Guide

Step 7: Determine Structural Number

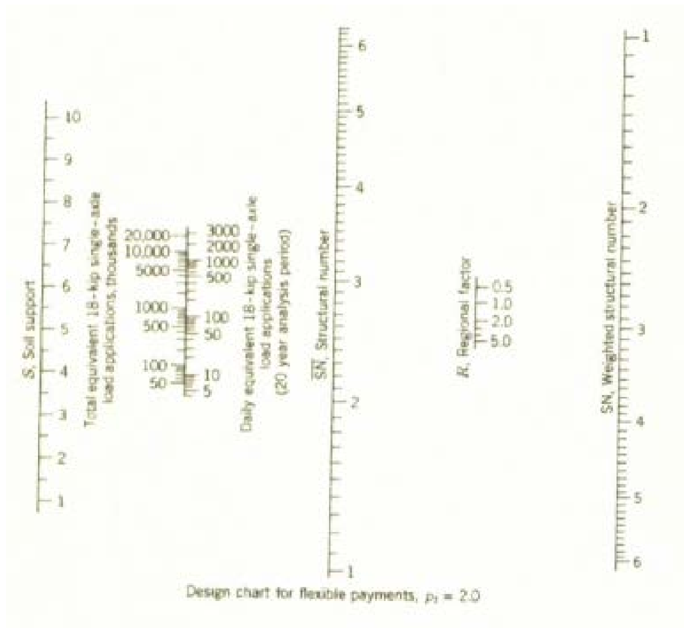


Figure 26: Nomograph to determine weighted structural number

Step 7 uses the Soil Support Value, the ESALs and the Regional factor to find the structural number on a nomograph. A line is drawn from the Soil Support axis through the ESAL axis and is extended to intersect the Structural Number$(\overline{SN})$. Then another straight line is drawn from the Structural Number through the regional factor axis and is extended to intersect the axis of the weighted structural number (SN). Once the structural number is determined, two simultaneous equations can be developed to determine an appropriate road design.

Case Studies

Case study roads are selected in order to compare the various road structures that each bituminous pavement design method will generate. All the bituminous pavement design methods will be analyzed to identify the limitations of each method when designing roads that will be surfaced with light surface treatments. Each case study will use multiple sources of evidence (converging lines of inquiry) to be evaluated (Yin, 1994). Interviews will be conducted with the county officials responsible for the road, the research team will perform site visits and additional research will be completed to find the information required for the pavement designs.

The roads selected for case study roads are located in different regions of the state of Minnesota and have different levels of traffic. The roads selected for case study roads are CSAH 14 in Becker County and CSAH 9 in Goodhue County

CSAH 14-Between CSAH 7 and CSAH 13

According to the information provided by Becker County:

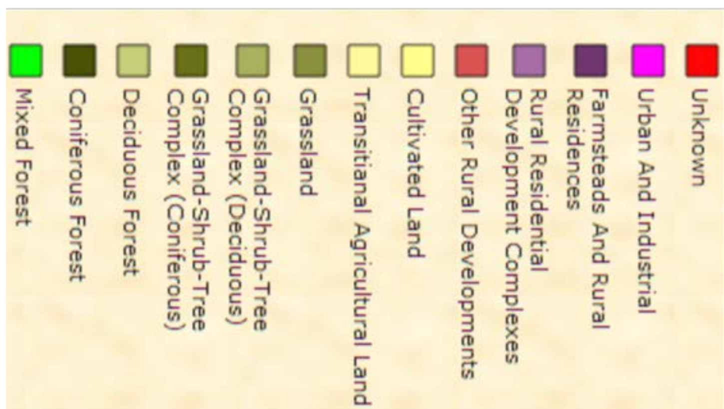
- Soil(or Sub grade) Factor= 100; Assumed R-Value=18
- AADT= 450

The existing layers of this road are listed below (total depth is 13.5”):

- Construct Bituminous Overlay (3”)
- In Place Bituminous (1 ½”)
- In Place Aggregate Base (9”)

Figure 27: CSAH 14-Picture taken on 8/14/13 by Francis Dayamba

Figure 28: Example of transverse cracking on CSAH 14-Picture taken on 8/14/13 by Francis Dayamba



Scale

1 in: 0.5 mi

North

Figure 29: Land use of the areas surrounding CSAH 14

Road Designs for CSAH 14

CSAH 14-GE Method-Ultimate 10-ton staged (9-ton) using soil factors

The most appropriate table to use in the chart above is the 9 Ton :< 150 HCADT. This table shows us that for a Soil Factor of 100 the Total GE is 17.5 and the Minimum Bit GE is 7.

In order to design the SFDR, two simultaneous equations will be developed. The first equation is based on the existing road structure:

[1] $T_{BS}+T_{AB}=13.5''$

T_{BS}=Thickness of Bituminous surfaces

T_{AB}=Thickness of Aggregate Base

The existing road section is shown in Figure30.

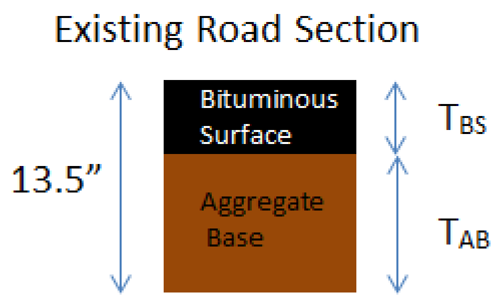


Figure 30: Diagram to show the existing road section

The second equation is derived from the GE Method and equations

The GE equation is (Labuz J. , 2012)

[2] $G.E. = a_1D_1 + a_2D_2$

G.E. = Total Granular Equivalent=17.5

a_1=G.E. Factor for Aggregate Base=1

D_1=Design Thickness of Bituminous surfaces=T_{BS}

a_2=G.E. Factor for SFDR=1.5[1]

17.5"= Total G.E.

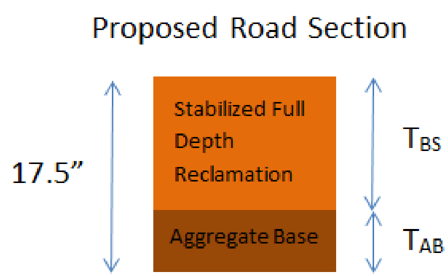


Figure 31: Diagram to show the proposed road section expressed in terms of GE values

[1]For the SFDR Factor, the research group chose to use 1.5 instead of 1 because the research group believes that an SFDR with a base stabilizer should provide more strength than an aggregate base.

D_2=Design Thickness of FDR=T_{AB}

All the values are substituted in Equation [2],

[3] $1.5*T_{BS}+1*T_{AB}=17.5$

This equation is illustrated in Figure.

When Equations [1] and [3] are solved as simultaneous equations then the following equation is derived

[3]- [1] = [4]

[4] $0.5*T_{BS}=4$

T_{BS} =8; As a result, T_{AB}=5.5

CSAH 14-Minnesota GE method-10 ton Flexible Pavement Design Using Soil Factors

The pavement design using soil factors can also be completed using a 10-ton design (Figure 20). The charts for the 10 ton design include a category of roads that are less than 1000 AADT (or 200,000 ESALs). In this category, the minimum Bit GE is 6 as opposed to 7(9-ton pavement design using soil factors). The total Effective GE for a soil factor of 100 is 16 and as a result the equations used to design the road are as follows:

[5] $T_{BS}+T_{AB}=13.5$”

[6] $1.5*T_{BS}+1*T_{AB}=16$

These equations produce a road design of **T_{BS}=5” and T_{AB}=8.5”**

This design requires a SFDR of 5” and an aggregate base of 8.5”.

CSAH 14-GE Method-Bituminous Pavement design chart

As mentioned previously, in order to use the chart it is required to find the ESALs over the design life and the R-Value of the soil beneath the road. Throughout the case study research, it was found that such a road would typically have an R-Value of 18. According to the

ESAL calculator(Figure32), the 20-year flexible forecast ESAL value is 367,000 and that is based on heavy commercial traffic values that are the default values on the excel sheet. The assumption considers that a typical rural road in Minnesota with AADT values between 301 and 750 will have certain percentages (Figure32) of trucks on the road.

Throughout our interviews of county and state officials, it was estimated that such a road would see approximately 200,000 ESALs throughout a 20-year period. Therefore the research group will consider pavement designs for CSAH 14 assuming that traffic loads were 367,000 ESALs and 200,000 ESALs.

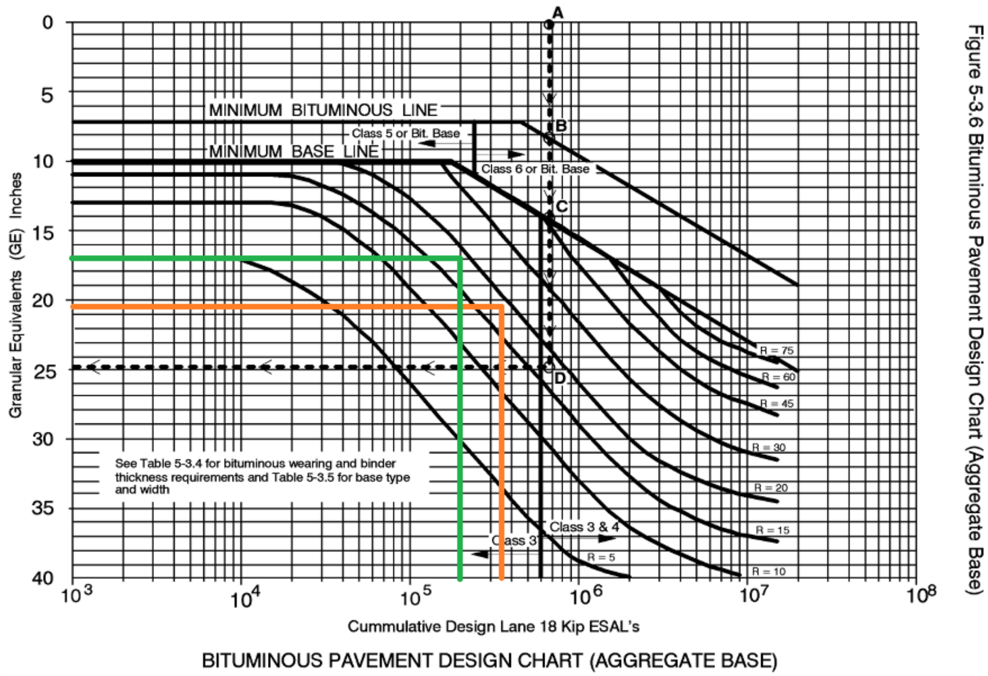
General Information	
Date	September 4th
Forecast Performed by	Francis Dayamba
Name of County or City	Becker County
Project Number	
Project Description	
Route Number	CSAH 14
Base Year (i.e. opening to traffic)	2014
Number of Lanes (both directions)	1
AADT Range	Rural: 301-750

Historical AADT (enter a minimum of two years)	Year	AADT
Enter oldest traffic data here	1996	450
Enter second oldest traffic data here	2005	450
Enter third oldest traffic data here		
Enter fourth oldest traffic data here		
Base Year AADT	2014	450
20-Year AADT	2034	450
35-Year AADT	2049	450
Growth Rate	0.00%	

Vehicle Type	Vehicle Class %	ESAL Factors	
		Flexible	Rigid
2AX-6TIRE SU	3.44%	0.25	0.24
3AX+SU	2.17%	0.58	0.85
3AX TST	0.39%	0.39	0.37
4AX TST	0.69%	0.51	0.53
5AX+TST	5.32%	1.13	1.89
TR TR, BUSES	1.40%	0.57	0.74
TWIN TRAILERS	0.03%	2.40	2.33
Total	**13.44%**	**NA**	**NA**

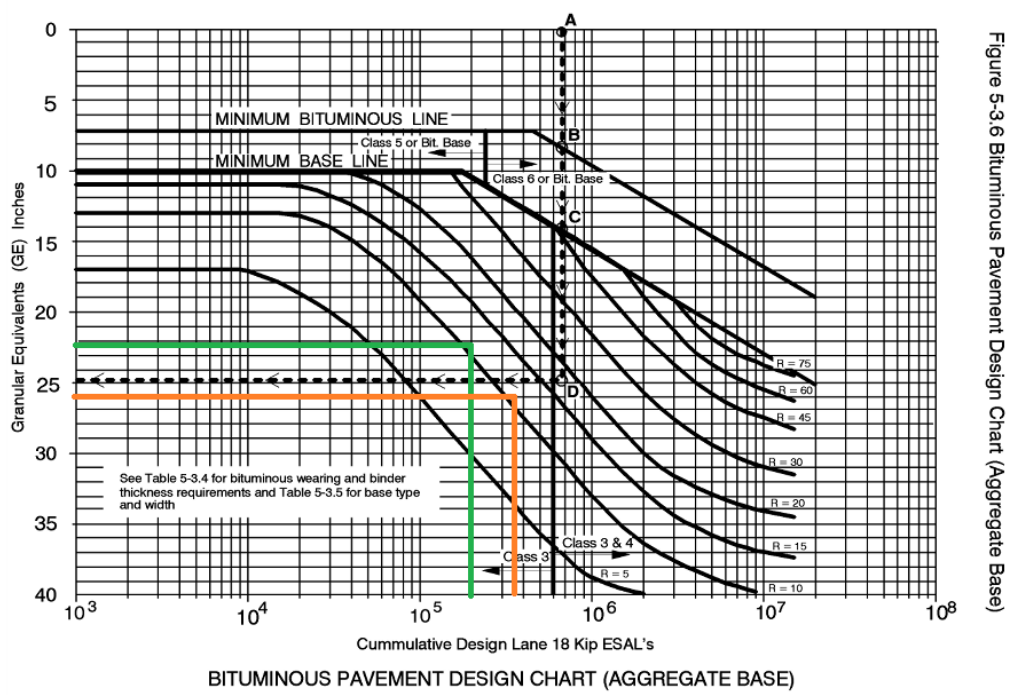
20-Year Flexible Forecast = 367,000
20-Year Rigid Forecast = 554,000
35-Year Flexible Forecast = 630,000
35-Year Rigid Forecast = 950,000

Figure 32: ESAL calculator using pre-determined percentages of heavy commercial traffic on rural road with traffic volume between 301-750 AADT



$2x10^5$ 3.6x10

Figure 33: Bituminous Pavement Design Chart to calculate the Total GE values required for 200,000 and 367,000 ESALs and R-value of 18



$2x10^5$3.6x10

Figure 34: Bituminous Pavement Design Chart to calculate the Total GE values required for 200,000 and 367,000 ESALs and R-value of 11

The Total GE required for 200,000 ESALs and an R-Value of 18 is 17 and the Total GE required for 367,000 ESALs is approximately 21(Figure33). In order to calculate the pavement thickness required by the stabilized full depth reclamation and the aggregate base, equations [1] and [2] will be used.

200,000 ESALs, R-Value of 18, Total Required GE=17

[1] $13.5''=T_{BS}+T_{AB}$

[2] $G.E. = a_1D_1 + a_2D_2$

$17=1.5*T_{BS}+T_{AB}$

$17=1.5 *T_{BS}+ 13.5 - T_{BS}$

$T_{BS}=7''; T_{AB}=6.5''$

367,000 ESALs, R-Value of 18, Total Required GE=21

[1] $13.5''=T_{BS}+T_{AB}$

[2] $G.E. = a_1D_1 + a_2D_2$

$21=1.5*T_{BS}+T_{AB}$

$21=1.5 *T_{BS}+ 13.5 - T_{BS}$

$7.5=0.5*T_{BS}$

$T_{BS}=15''; T_{AB}=-1.5$

The Total GE required for 200,000 ESALs and an R-Value of 11 is 22 and the Total GE required for 367,000 ESALs is 26. Equations [1] and [2] will be used to find the required thickness of the SFDR and the aggregate base.

200,000 ESALs, R-Value of 11, Total Required GE=22

[1] $13.5''=T_{BS}+T_{AB}$

[2] $22=1.5*T_{BS}+T_{AB}$

$T_{BS}=17''; T_{AB}=-3.5$

367,000 ESALs, R-Value of 11, Total Required GE=26

[1] 13.5"=T_{BS}+T_{AB}

[2] 26=1.5*T_{BS}+T_{AB}

T_{BS}=25"; T_{AB}=-11.5

Based on the results, the research group proceeded to apply equations [1] and [2] to varying GE values to determine the highest GE value where the required depth of the SFDR does not extend past the depth of the aggregate base (i.e. values of T_{BS} where T_{AB} is not a negative number).

Table 13: GE Values to which equations [1] and [2] can be applied without applying an SFDR at a depth further

Total G.E.	Thickness of SFDR(inches)	Thickness of Aggregate Base(inches)
17	7	6.5
18	9	4.5
19	11	2.5
20	13	0.5
21	SFDR Depth > T_{BS} + T_{AB}	T_{AB}< 0

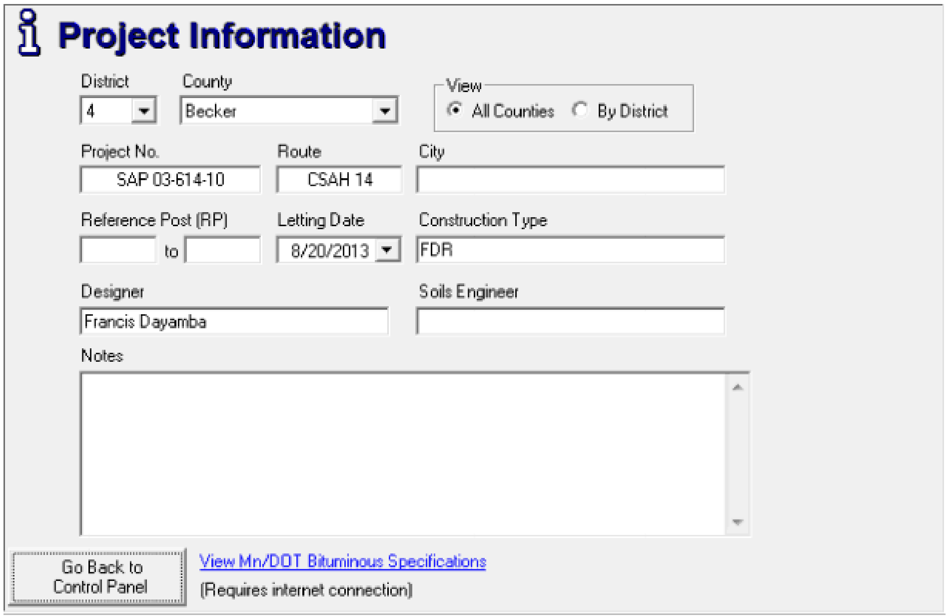
20 is the highest Total GE value that can be applied with these equations. For GE values higher than 20, users should consider using a different design method or increasing the depth of the road by adding aggregate to the SFDR.

The charts specify that the minimum bituminous GE is 7.This minimum total GE requires the depth of the bituminous to be thicker than 3". This feature within the tables does not apply to roads designed to provide structure for a light surface treatment.

CSAH 14-Mechanistic-Empirical method using computer software (MnPave)

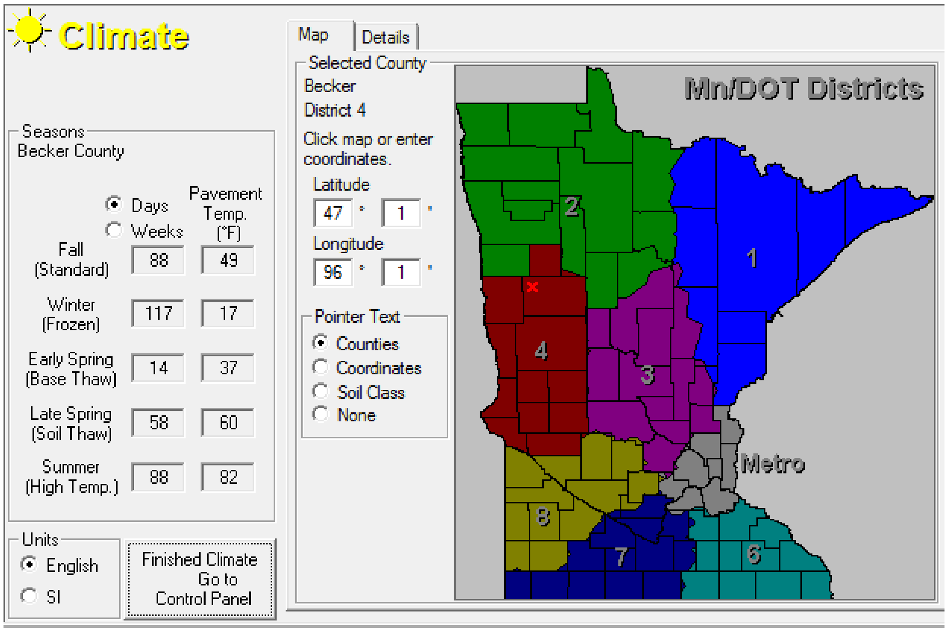
The information entered into the MnPave software is shown below:

1. Project Information



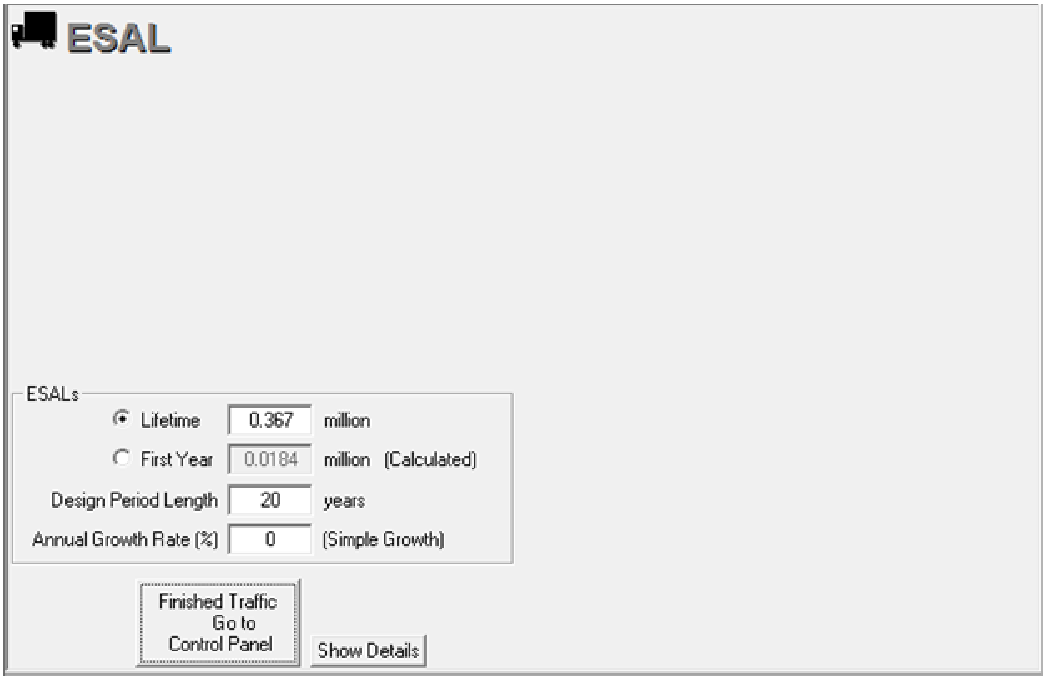
2. Climate

Clicked on the location of the road on the Minnesota map

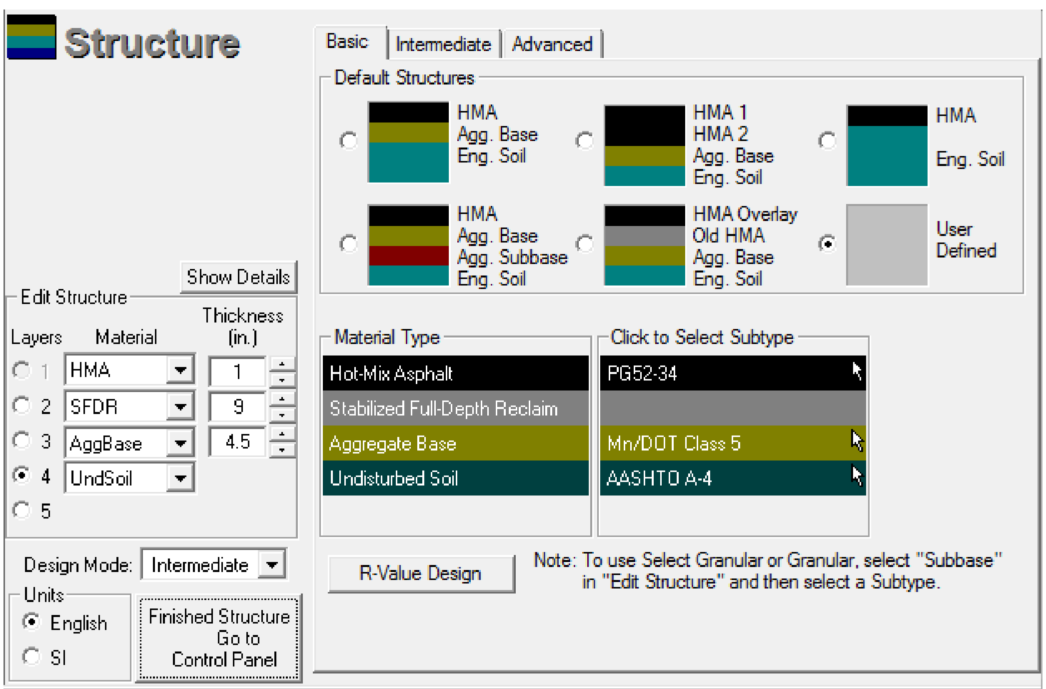


3. Traffic

200,000 and 367,000 ESALs over a 20-year period were the ESAL values inputted into the software.



4. Structure



Intermediate

Defined Structure: User Defined

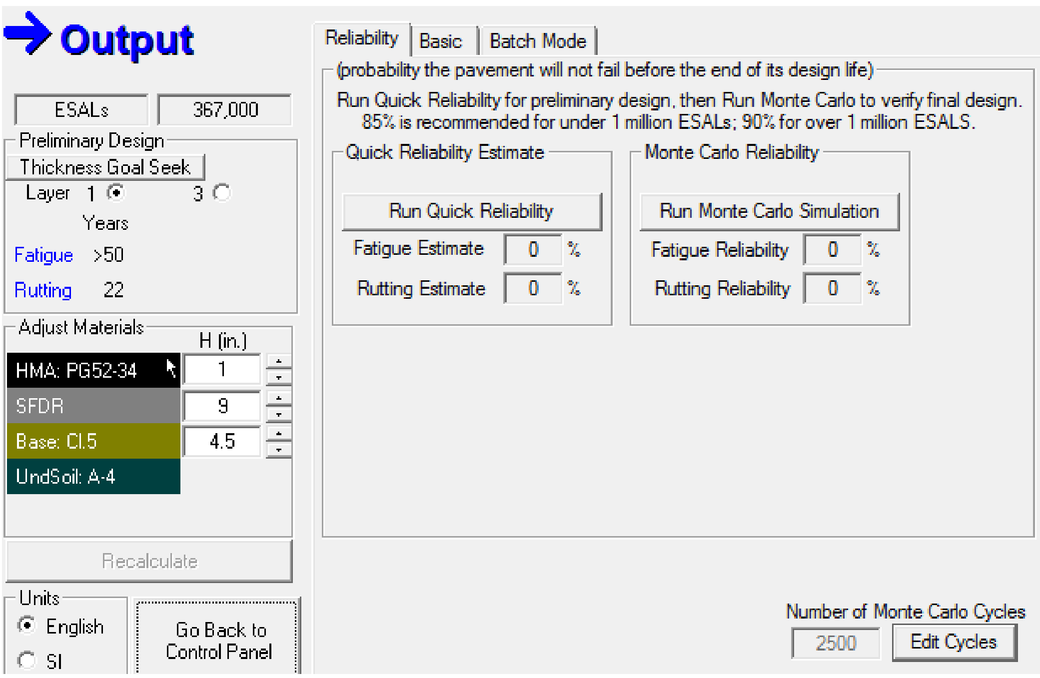
Hot Mix Asphalt (PG 58-34)

Stabilized Full Depth Reclamation

Aggregate Base (Class 5)

Undisturbed Soil (A-4)

5. Output



The model can be developed using the basic, intermediate, or advanced settings. These results have been generated using the basic setting. The authors do not have access to the information required to use the advanced settings. The main difference between the basic and intermediate setting is that the intermediate setting allows the user to enter the R-Value for the soil.

Table 14: Iterations of M-E Method using 200,000 ESALs and 1" layer of HMA

Iterations			Outputs	
HMA: PG52-34	Stabilized Full Depth Reclamation	Aggregate Base	Fatigue (Years)	Rutting (Years)
1	**5**	**8.5**	**>50**	**22**
1	4	9.5	>50	19
1	3	10.5	>50	17

Table 15: Iterations of M-E Method using 367,000 ESALs and 1" layer of HMA

Iterations			Outputs	
HMA: PG52-34	Stabilized Full Depth Reclamation	Aggregate Base	Fatigue (Years)	Rutting (Years)
1	**9**	**4.5**	**>50**	**22**
1	8	5.5	>50	19
1	7	6.5	>50	16
1	6	7.5	>50	14
1	5	8.5	>50	12
1	4	9.5	>50	10
1	3	10.5	>50	9

If the ESALS on the road are 200,000 throughout a 20-year design period then the road should last for at least 23 years without failing in rutting. However, if the ESALs on the road are 367,000 ESALs, all the road designs with less than 7" for an SFDR would fail in rutting before the expected design life(20 years).The program does not clearly define the depth of the rutting before failure is considered to have occurred.

CSAH 14-AASHTO Method using nomographs

Step 1: Calculate the ESALs

The ESALs for heavy traffic on CSAH 14 have been calculated to be 200,000 and 367,000.

Step 2 and Step 3: Determine CBR

The soils factor (SF) for the sub grade is 100. These soils are classified as either A-4(Silt, Silt with Sand) or A-6(Lean Clay) according to the flexible pavement design charts. According to Table 11 , the CBR values for these soils are between 10-20 and 5-15 respectively. The research group chose to select a CBR value of 13 for the purpose of these calculations. The value of 13 satisfies both ranges.

An alternative method to find the soil types is to use a soil type map (Figure 35) to determine the soil value. The figure above shows the soil types beneath CSAH 14.The soil types beneath the road are: Complex, Depressional Complex, Muck, Mucky Silt Loam and Silty Clay Loam. For the purpose of this investigation, Complex soil will be assumed to be a soil similar to glacial till. The user must then decide which soil is the most predominant below the road and select a soil to consider for the calculations. Once the user selects a soil type, then they can use the two tables below to find the corresponding CBR values.

Step 4: Find Soil Support Value

In order to find the Soil Support Value, the user can use the CBR value found in Step 3 or the R Value of the soil. A perpendicular line is drawn from the CBR (or R-Value) axis to the Soil Support Value axis. The soil support value that corresponds to the CBR value is 6.5. The corresponding Soil Support Value for the R-Values of 11 and 18 are 3.5 and 4.25 respectively.

R-Values of 11 and 18 were used to complete road designs for the GE Method using the pavement design chart.

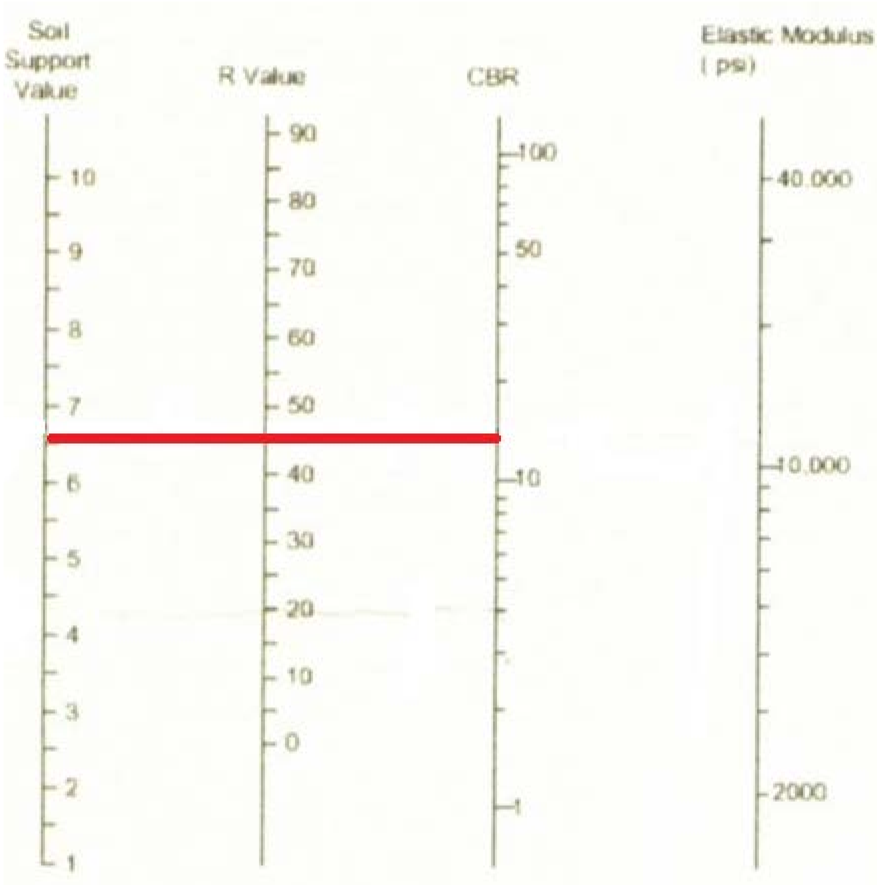


Figure 35: Chart to convert various soil classifications

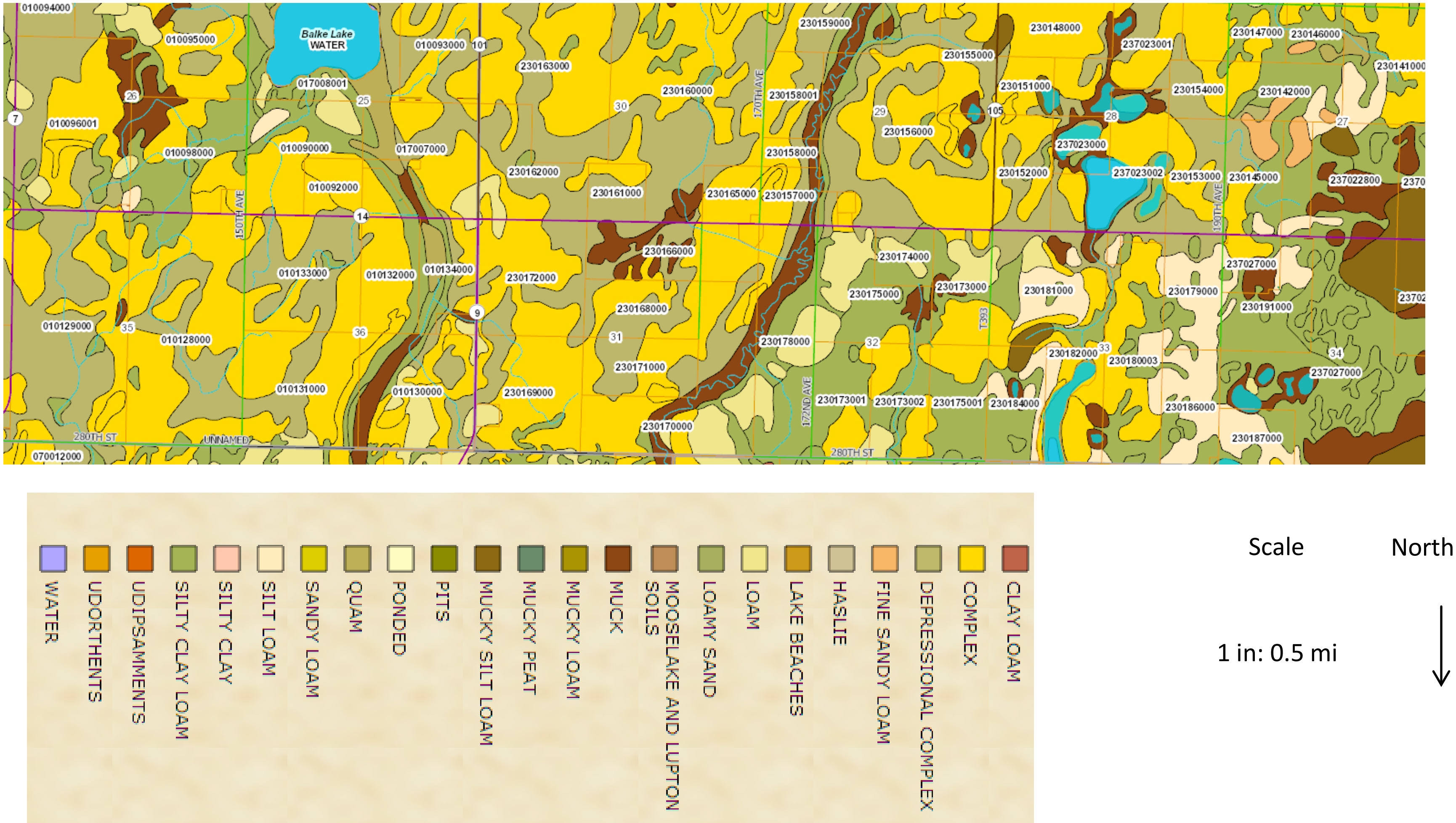
Step 5: Find Structural Coefficients

The coefficients used for the SFDR and Aggregate base are 0.32 and 0.07 respectively.

Step 6: Regional Factor

The road is located in regional factor 3.

Step 7: Find the required structural depth



Information obtained through the Interactive GIS MAP-Available through the Becker County Website

Figure 36: Soil Map of the areas surrounding CSAH 14

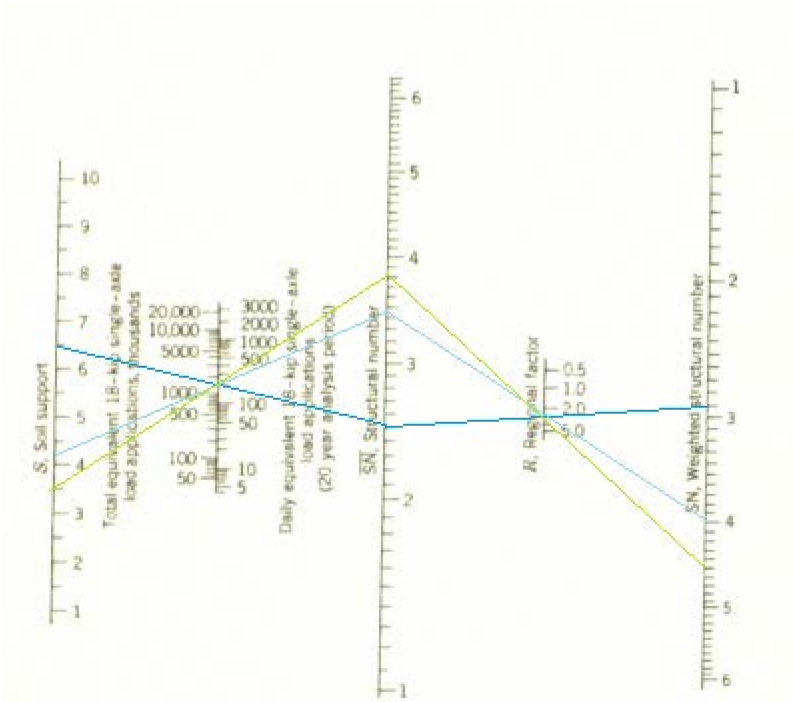


Figure 37: Nomograph to show the process to finding the weighted structural number assuming 200,000 ESALs

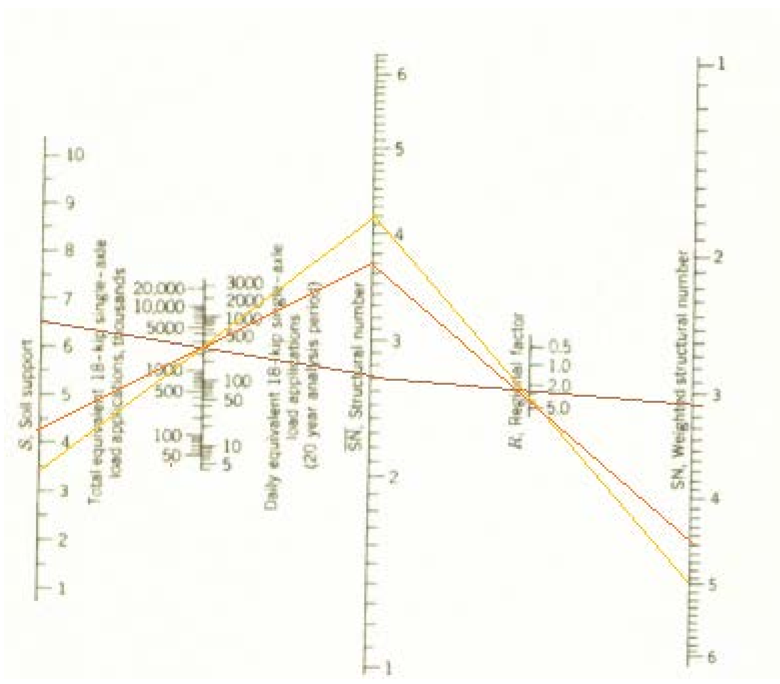


Figure 38: Nomograph to show the process to finding the weighted structural number assuming 367,000 ESALs

Six iterations of soil conditions and ESALs were used to show how various assumptions can affect the required SFDR depths. The answers are shown in Table 16 and the corresponding nomographs are shown in Figure 37 and Figure 38.

Table 16: Results of AASHTO Design Method

ESALS	Soil Support Value	Structural Number(SN)	Depth of SFDR(T_{BS})	Depth of Aggregate Base(T_{AB})
200,000-CBR Value of 13	6.5	2.9	8"	5.5"
200,000-R-Value of 11	4.25	4	12"	1.5"
200,000-R-Value of 11*	3.5	4.4	14"	-0.5"
367,000-CBR Value of 13	6.5	3.1	8.5"	5"
367,000-R-Value of 18*	4.25	4.4	14"	-0.5"
367,000-R-Value of 11*	3.5	4.9	16"	-2.5"

Table 17: Results of all design methods used to design CSAH 14, Becker County

	ESALs-20-Year	Depth of SFDR(T_{BS})	Depth of Aggregate Base(T_{AB})
GE Method-9-Ton Design using SF of 100	400,000 (150 HCAADT)	8"	5.5"
GE Method-10-Ton Design using SF of 100	200,000	5"	8.5"
GE Method-10 Ton Design using Pavement Design Chart-R Value of 18	200,000	7"	6.5"
AASHTO Method-R-Value of 18	200,000	12"	1.5"
GE Method-10 Ton Design using Pavement Design Chart-R Value of 11	200,000	17"	-3.5"
AASHTO Method-R-Value of 11	200,000	14"	-0.5"
Mechanistic-Empirical- A-4 Soil	200,000	5"	8.5"
AASHTO Method-CBR Value of 13	200,000	8"	5.5"
GE Method-10 Ton Design using Pavement Design Chart-R Value of 18	367,000	15"	-1.5"
AASHTO Method-R-Value of 18	367,000	14"	-0.5"
GE Method-10 Ton Design using Pavement Design Chart-R Value of 11	367,000	25"	-11.5"
AASHTO Method-R-Value of 11	367,000	16"	-2.5"
Mechanistic-Empirical- A-4 Soil	367,000	9"	4.5"
AASHTO Method-CBR Value of 13	367,000	8.5"	5"

CSAH 10-Between T.H. 58 and CO. RD 48

The section of road that will be considered throughout the case study is ST 23+20 to STA 73+92.

Below is information provided by Goodhue County.

- R-Value=20;
- AADT 2013 = 1,562
- Heavy Commercial Traffic= 4%

The existing layers of this road are listed below

- Existing Bituminous(7")
- Class 3 (4")
- Granular Base (8")

Figure 39: CSAH 10-Picture taken on 8/15/13 by Francis Dayamba

Figure 40: Close-up picture of CSAH 10-Picture taken on 8/15/13 by Francis Dayamba

Figure 41: Picture of CSAH 10 near the urban designation-Picture taken 8/15/13 by Francis Dayamba

Figure 42: Land use in the area surrounding CSAH 10

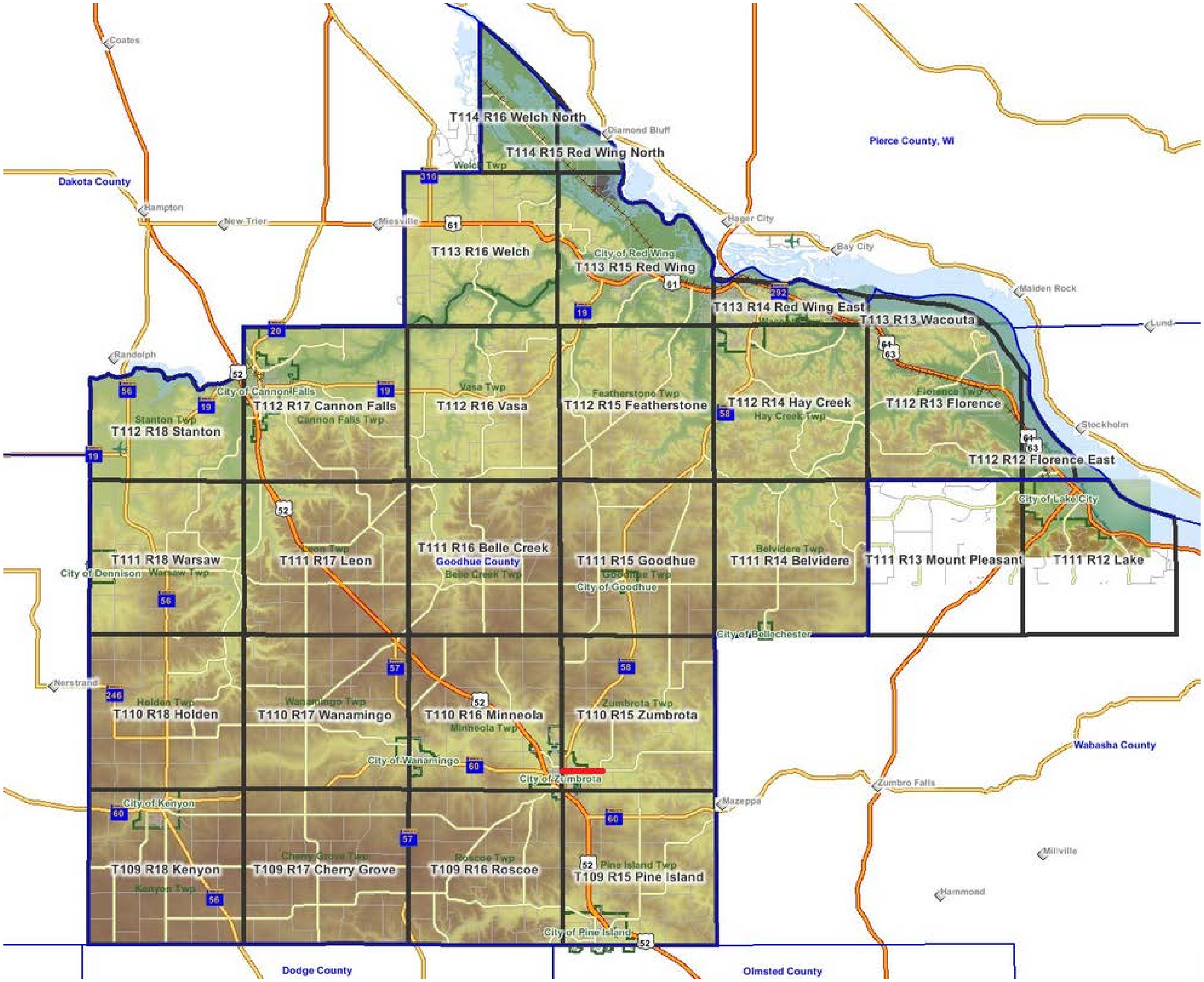


Figure 43: Map of Goodhue County (CSAH 10 highlighted in bright red)

Road Designs for CSAH 10

CSAH 10-GE Method-Ultimate 10-ton staged (9-ton) using soil factors

In order to use this method, the first step is to solve for the HCAADT for the case study road. The AADT for CSAH 10 is 1,562 and the percentage of heavy commercial traffic is 4%.

$1{,}562 * 0.04 = 63\ HCAADT$

As a result, the most appropriate table to use is the 9 Ton Staged: < 150 HCADT. The first equation is developed based on the existing road structure:

$[1]\ T_{BS} + T_{AB} + T_S = 19''$

T_{BS}=Thickness of Bituminous surfaces=Depth of FDR

T_{AB}=Thickness of Aggregate Base

T_S=Thickness of Sub-base

The second equation is derived from the GE Method and equations

The GE equation (Labuz J. , 2012)is:

$[2]\ G.E = a_1D_1 + a_2D_2 + a_3D_3$

Since the condition of the soil is expressed in terms of an R-value, the author needs to convert the R-Value into a Soil Factor to design the road using this method. According to Table 10, an R-Value of 14 is equivalent to a MN/DOT soil factor between 120 and 130. It appears to be closer to 120, so for this investigation a value of 120 will be assumed as the soil factor. According to the 9 Ton Staged: < 150 HCADT chart, the total GE needed for the road is 20.5.

Equations [1] and [2] become the following:

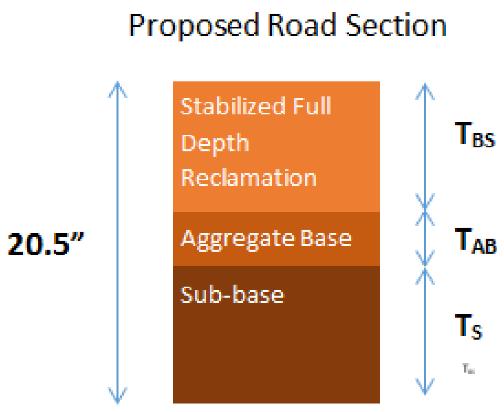
$[1] T_{BS} + T_{AB} + 8 = 19$

$[2]\ 20.5 = a_1 D_1 + a_2 D_2 + 0.5 * 8$

$[1] T_{BS} + T_{AB} = 11$

$[2]\ 16.5 = a_1 D_1 + a_2 D_2$

$[2]\ 16.5 = 1.5 T_{BS} + T_{AB}$



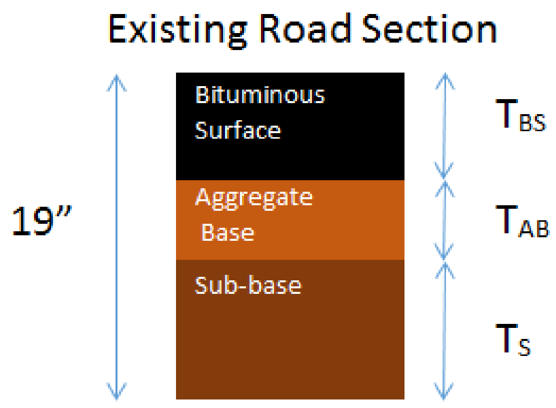


Figure 45: Diagram to show the existing road section

Figure 44: Diagram to show the proposed section in terms of GE values

Solve Equations [1] and [2]

T_{BS}=11” and T_{AB}=0”

This answer suggests that an SFDR should be applied for the entire thickness of the bituminous surface in order to have sufficient structural support.

CSAH 10-GE Method- 10-ton using soil factors

These tables require a total GE of 21 for a Soil Factor of 120 for traffic levels less than 150 HCAADT.

Therefore equations [1] and [2] are now:

$[1] T_{BS} + T_{AB} = 11$

$[2]\ 21 = a_1 D_1 + a_2 D_2 + 0.5 * 8$

$[2]\ 17 = 1.5 T_{BS} + T_{AB}$

Solve Equations [1] and [2]

T_{BS}=12"

T_{AB}=-1"

This answer suggests that an SFDR should be applied for the entire thickness of the bituminous surface and 1" of the aggregate base in order to provide sufficient structural support.

CSAH 10-Minnesota GE Method-Bituminous Pavement design chart

In order to use the pavement design chart, the user must calculate the ESALs of heavy traffic. The ESAL calculator provided by MN/DOT was used to determine three ESAL values based on different assumptions. The first ESAL value is based on a national average of heavy traffic that applies to roads in particular settings. For example, the ESAL calculator assumes that a road in a rural area with traffic between 751-1500 AADT has the heavy commercial traffic shown in the table below. When these percentages are used to calculate the ESALs, the ESAL calculator determines that 551,000 ESALs travel on CSAH 10 over a 20-year period.

Table 18: Assumed percentages of heavy traffic for rural roads between 751-1500 AADT

Vehicle Type	Vehicle Class (%)
2AX-6TIRE SU	3.69%
3AX+SU	1.71%
3AX TST	0.33%
4AX TST	0.57%
5AX+TST	2.10%
TR TR, BUSES	1.03%
TWIN TRAILERS	0.02%
Total	**9.45%**

ESALs = 551,000

$[1] T_{BS} + T_{AB} = 11"$

$[2]\ 22 = a_1 D_1 + a_2 D_2 + 0.5 * 8$

$[2]\ 18 = 1.5 T_{BS} + T_{AB}$

T_{BS}=14; T_{AB}=-3

This answer suggests that an SFDR should be applied for the entire thickness of the bituminous surface and 3" of the aggregate base in order to have sufficient structural support.

Based on the information provided by the county, CSAH 10 is 4 percent heavy commercial traffic. The authors determined that a reasonable method to calculate the percentage of heavy traffic is to use the ratio of the traffic levels outlined in Table18 but apply these ratios to 4 percent heavy commercial traffic (Table 19).

Table 19: Traffic percentages assuming 4 percent heavy commercial traffic

Vehicle Type	**Vehicle Class (%)**
2AX-6TIRE SU	1.56%
3AX+SU	0.72%
3AX TST	0.14%
4AX TST	0.24%
5AX+TST	0.89%
TR TR, BUSES	0.44%
TWIN TRAILERS	0.01%
Total	**4%**

The ESAL calculator found the ESALs to now be 234,000 over a 20-year period.

ESALs = 234,000

$[1] T_{BS} + T_{AB} = 11"$

$[2]\ 17 = a_1 D_1 + a_2 D_2 + 0.5 * 8$

$[2]\ 13 = 1.5 T_{BS} + T_{AB}$

Solve Equations [1] and [2]

$T_{BS}=4; T_{AB}=7$

This answer suggests that an SFDR should be applied for 4" of the bituminous surfacing in order to have sufficient structural support.

General Information

Date	October 3rd 2013	
Forecast Performed by		
Name of County or City	Goodhue	
Project Number		
Project Description		
Route Number	CSAH 10	
Base Year (i.e. opening to traffic)	2013	
Number of Lanes (both directions)	1	
AADT Range	Rural: 751-1500	
Historical AADT (enter a minimum of two years)	**Year**	**AADT**
Enter oldest traffic data here	2013	1,198
Enter second oldest traffic data here	2014	1,198
Enter third oldest traffic data here		
Enter fourth oldest traffic data here		
Base Year AADT	2013	1,200
20-Year AADT	2033	1,200
35-Year AADT	2048	1,200
Growth Rate	0.00%	

Vehicle Type	Vehicle Class %	ESAL Factors Flexible	Rigid
2AX-6TIRE SU	3.69%	0.25	0.24
3AX+SU	1.71%	0.58	0.85
3AX TST	0.33%	0.39	0.37
4AX TST	0.57%	0.51	0.53
5AX+TST	2.10%	1.13	1.89
TR TR, BUSES	1.03%	0.57	0.74
TWIN TRAILERS	0.02%	2.40	2.33
Total	**9.45%**	**NA**	**NA**

20-Year Flexible Forecast = 551,000
20-Year Rigid Forecast = 777,000
35-Year Flexible Forecast = 944,000
35-Year Rigid Forecast = 1,333,000

Figure 46: ESALs over a 20-year period using an estimated percentage of traffic of each vehicle class is 551,000

General Information

Date	October 3rd 2013
Forecast Performed by	
Name of County or City	Goodhue
Project Number	
Project Description	
Route Number	CSAH 10
Base Year (i.e. opening to traffic)	2014
Number of Lanes (both directions)	1

Historical AADT (enter a minimum of two years)	Year	AADT
Enter oldest traffic data here	2013	1,198
Enter second oldest traffic data here	2014	1,198
Enter third oldest traffic data here		
Enter fourth oldest traffic data here		
Base Year AADT	2014	1,200
20-Year AADT	2034	1,200
35-Year AADT	2049	1,200
Growth Rate	0.00%	

Vehicle Type	Vehicle Class %	ESAL Factors	
		Flexible	Rigid
2AX-6TIRE SU	1.56%	0.25	0.24
3AX+SU	0.72%	0.58	0.85
3AX TST	0.14%	0.39	0.37
4AX TST	0.24%	0.51	0.53
5AX+TST	0.89%	1.13	1.89
TR TR, BUSES	0.44%	0.57	0.74
TWIN TRAILERS	0.01%	2.40	2.33
Total	**4.00%**	**NA**	**NA**

20-Year Flexible Forecast =	**234,000**
20-Year Rigid Forecast =	**330,000**
35-Year Flexible Forecast =	**400,000**
35-Year Rigid Forecast =	**565,000**

Figure 47: ESALs assuming 4 percent heavy commercial traffic

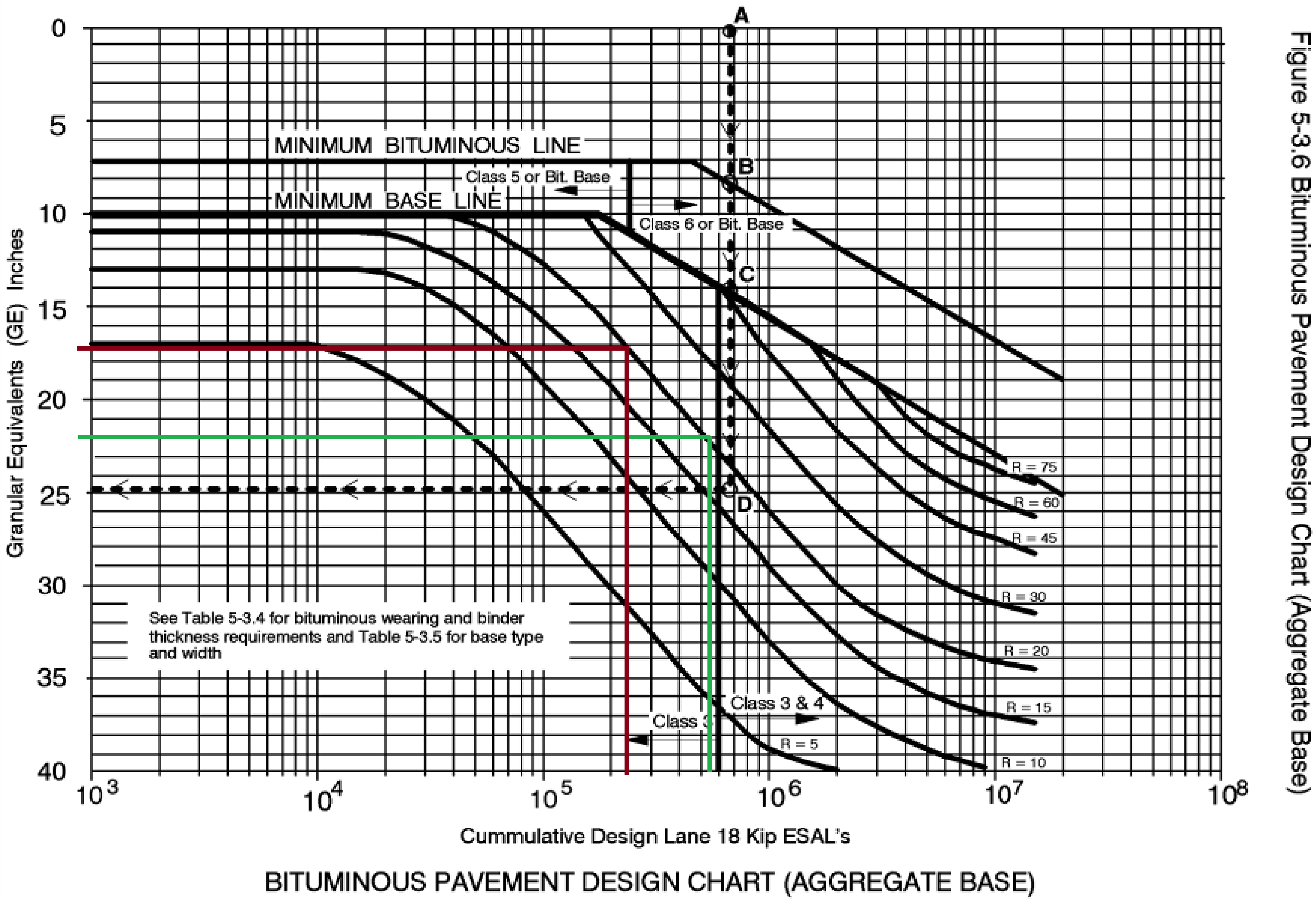


Figure 48: Bituminous Pavement Design Chart for CSAH 10

CSAH 10-Mechanistic Empirical Method using computer software (MnPave)

Table 20: Table to show iterations when assuming 551,000 ESALs for CSAH 10

Iterations			Outputs	
HMA: PG52-34	Stabilized Full Depth Reclamation	Aggregate Base	Fatigue (Years)	Rutting (Years)
1	**6**	**5**	**>50**	**21**
1	5	6	>50	18
1	4	7	>50	15
1	3	8	>50	13
1	2	9	>50	11
1	1	10	>50	9

Table 21: Table to show iterations when assuming 234,000 ESALs for CSAH 10

Iterations			Outputs	
HMA: PG52-34	Stabilized Full Depth Reclamation	Aggregate Base	Fatigue (Years)	Rutting (Years)
1	**1**	**10**	**>50**	**22**

CSAH 10-AASHTO Method using nomographs

Step 1: Calculate the ESALs

Figure 46 and Figure 47 show the information entered into the ESAL calculator to find the heavy traffic ESALs. The values found are 551,000 and 234,000.

Step 2 and Step 3: Determine CBR

The sub grade soils beneath the road are described as lean clays. According to Table 11, the CBR % would range between 5-15 %. The author selected 10 %. The CBR determined from the Figure is approximately 12.

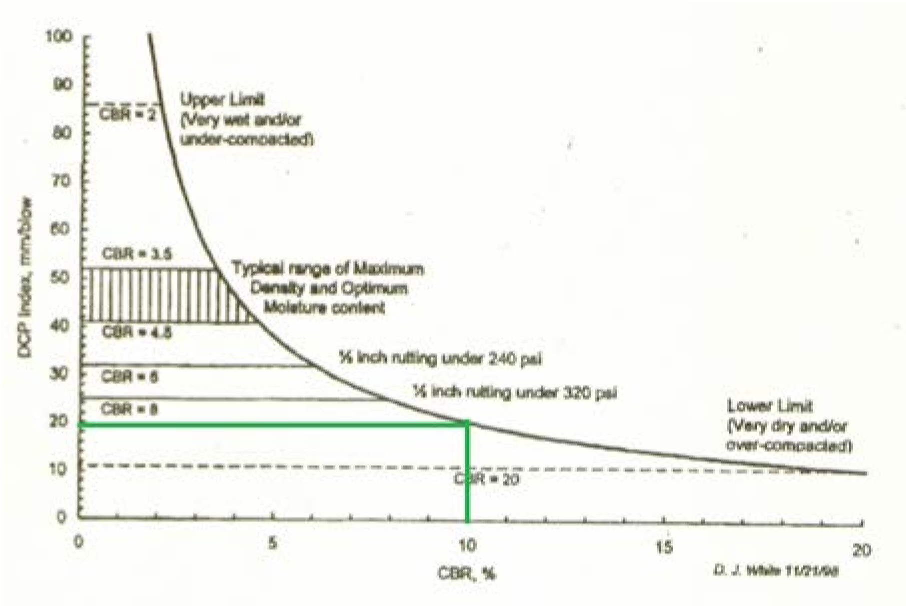


Figure 49: Iowa DOT DCIP Index Guidelines Chart (White 2000) for CSAH 10

Step 4: Find Soil Support Value

The CBR value is then used to find the Soil Support Value.

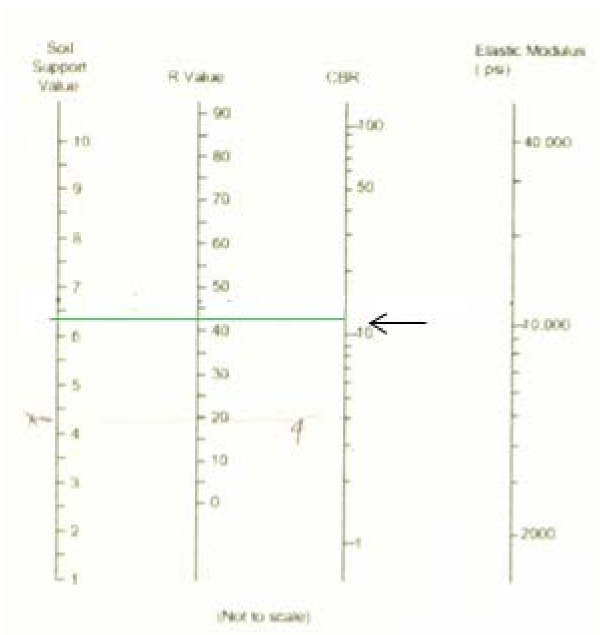


Figure 50: Illustration of How Soil Support is determined Pre 1986 AASHTO guide for CSAH 10

Step 5: Find Structural Coefficients

The coefficients used for the SFDR and Aggregate base are 0.32 and 0.07 respectively.

Step 6: Regional Factor

The road is located in regional factor 3.

Step 7: Determine Structural Number

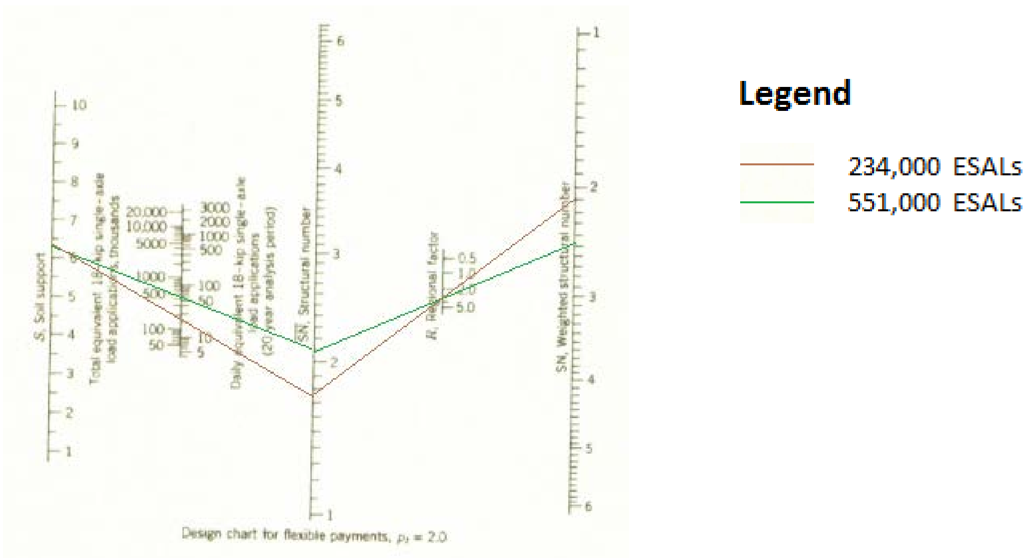


Figure 51: AASHO 1972 Flexible Pavement Design Nomograph for CSAH 10

ESALs 551,000

[4]$0.32T_{BS} + 0.07T_{AB}$ =2.45

[1] $T_{BS} + T_{AB} + 8 = 19$”

[1] $T_{BS} + T_{AB} = 11$

Solve Equations 1 and 4

[1] - [4] X 3.125 =

$0.78125T_{AB} = 3.343$

$T_{AB} = 4.2$ Approximately 4.5”

$T_{BS} = 6.5$

This answer suggests that an SFDR should be applied for 6.5” of the bituminous surfacing in order to have sufficient structural support.

ESALs 234,000

$[5] 0.32T_{BS} + 0.07T_{AB} = 2.1$

$[1]\ T_{BS} + T_{AB} = 11$

Solve Equations 1 and 4

[1] - [4] X 3.125 =

$0.78125T_{AB} = 5.0625$

$T_{AB} = 5.6$ Approximately 5.5”

$T_{BS} = 5.5$

This answer suggests that an SFDR should be applied for 5.5” of the bituminous pavement in order to have sufficient structural support.

Table 22: Results all design methods used to design CSAH 10, Goodhue County

	ESALs-20-Year	Depth of SFDR(T_{BS})	Depth of Aggregate Base(T_{AB})
GE Method-9-Ton Design using SF of 120	400,000 (150 HCAADT)	11	0
GE Method-10-Ton Design using SF of 120	200,000	12	-1
GE Method-10 Ton Design using Chart-R Value of 20	234,000	4	7
Mechanistic-Empirical- A-4 Soil	234,000	1	10
AASHTO Method-R-Value of 20	234,000	5.5	5.5
GE Method-10 Ton Design using Chart-R Value of 20	551,000	14	-3
Mechanistic-Empirical- A-4 Soil	551,000	6	5
AASHTO Method-R-Value of 20	551,000	6.5	4.5

Road designs using design methods discussed in literature review

The design methods discussed in the literature review are both design methods developed to design road structures that will support LSTs in developing countries. As a part of the methodology, the author used both design methods to design the case study roads.

The design method developed by Rolt requires the user to choose a chart that represents the surfacing option that the user plans to build. The options of the surfaces are shown in Table 23. There are eight charts to choose from and four (Charts 1, 2, 7 and 8) of the charts propose surface dressings (LSTs). None of these four charts include a stabilized full depth reclamation layer as an option for a road base. Amongst the four charts, the authors determined that Chart 7 provides road base options that are the best match with an SFDR. Chart 7 produces designs with layers that consist of both bituminous road base and granular material.

Once the chart is chosen, the user must select an appropriate ESAL value and a CBR (%) value. The final step is to use the chart to select the design that corresponds to the ESAL and the CBR (%) values.

CHART 7 BITUMINOUS ROADBASE / SEMI-STRUCTURAL SURFACE

	T1	T2	T3	T4	T5	T6	T7	T8
S1				SD 150 200 350	50 125 225* 350	50 150 225* 350	50 175 225* 350	50 200 250* 350
S2				SD 150 200 200	50 125 225* 200	50 150 225* 200	50 175 225* 200	50 200 250* 200
S3				SD 150 250	50 125 250	50 150 275*	50 175 275*	50 200 275*
S4				SD 150 175	50 125 200	50 150 200	50 175 200	50 200 200
S5				SD 150 125	50 125 125	50 150 125	50 175 125	50 200 125
S6				SD 150	50 125	50 150	50 175	50 200

Note: 1 * Up to 100mm of sub-base may be substituted with selected fill provided the sub-base is not reduced to less than the roadbase thickness or 200mm whichever is the greater. The substitution ratio of sub-base to selected fill is 25mm : 32mm.

2 A cement or lime-stabilised sub-base may also be used but see Section 7.7.2.

Figure 52: Chart 7 from the Rolt's method

Table 23: Summary of material requirements for the design charts

CHART NO	SURFACING	ROADBASE	REFER CHAPTI
1	Double surface dressing	T1-T4 use GB1,GB2 or GB3 T5 use GB1,A or GB1,B T6 must be GB1,A	6 and
2	Double surface dressing	T1-T4 use GB1, GB2 or GB3 T5 use GB1 T6,T7,T8 use GB1,A	6, 7 an
3	'Flexible' asphalt	T1-T4 use GB1 or GB2 T5 use GB1 T6 use GB1,A	6 and
4	'Flexible' asphalt	T1-T4 use GB1 or GB2 T5 use GB1 T6-T8 use GB1,A	6, 7 an
5	Wearing course and basecourse	GB1,A	6 and
6	Wearing course and basecourse	GB1 or GB2	6, 7 an
7	High quality single seal or double seal for T4. 'Flexible' asphalt for T5-T8	RB1, RB2 or RB3	8 and
8	Double surface dressing	CB1, CB2	7 and

The design method developed by Russell uses the ESALs and the CBR (%) to determine the appropriate road structure. Figure 53 shows the chart that is used to design the road structure for an LST using the Russell method. Both methods reference the term "surface dressing". A "surface dressing" is equivalent to a light surface treatment.

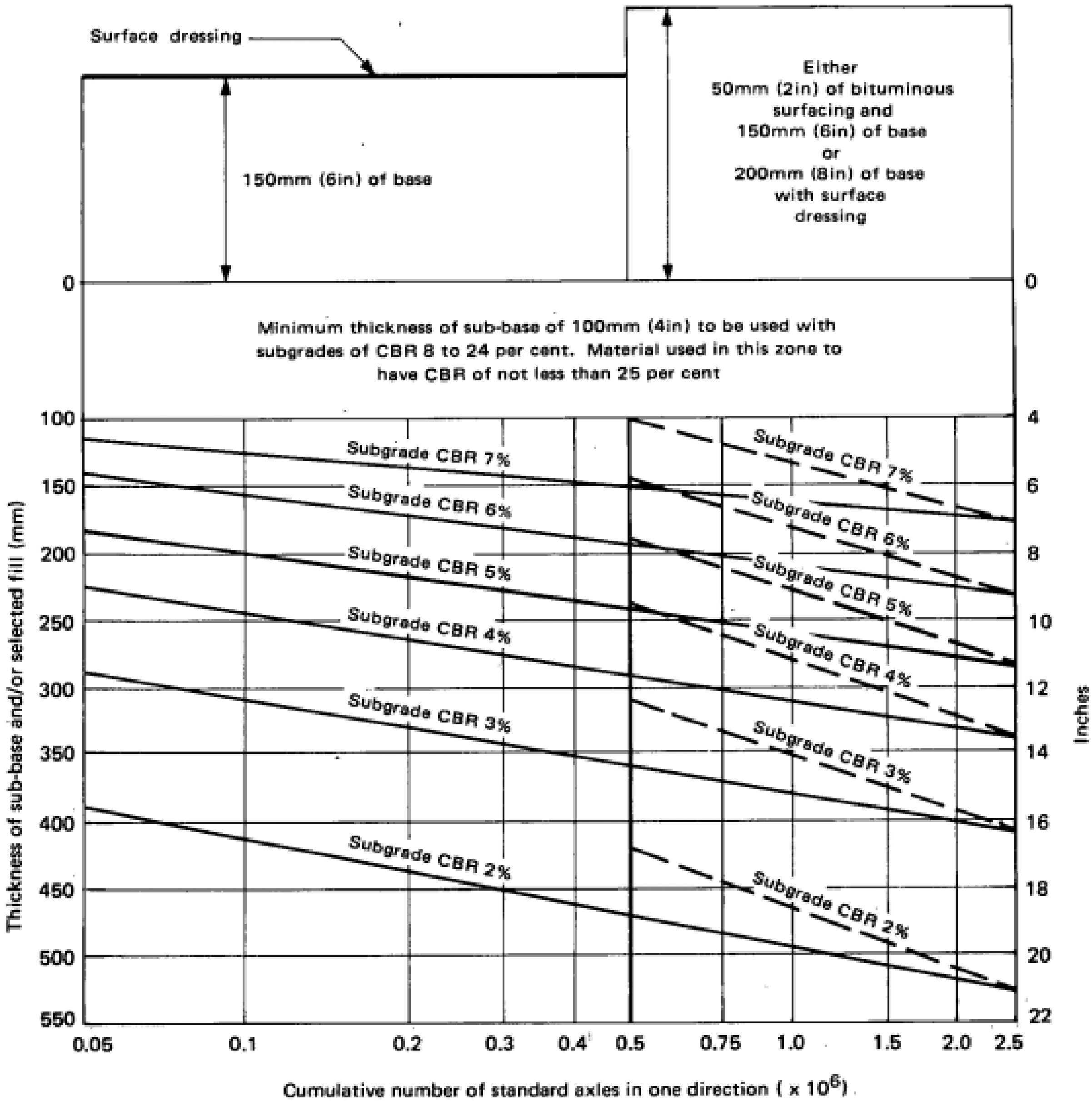


Figure 53: Pavement design chart for LSTs (surface dressing) and flexible pavements (Russell's method)

Rolt’s and Russell’s Method

Rolt’s method and Russell’s method are now used to design the case study roads CSAH 14 and CSAH 10.

<u>CSAH 14</u>

Rolt’s method

Chart 7

ESALs= 367,000(

Figure32)

Traffic classes= T2

CBR (%) = 13(CSAH 14-AASHTO Method using nomographs)

Sub grade strength classes= S4

There is no road design that falls within this quadrant (Figure 52). As a result, the design method with the least structure required for a road with a sub grade class of S4 is selected.

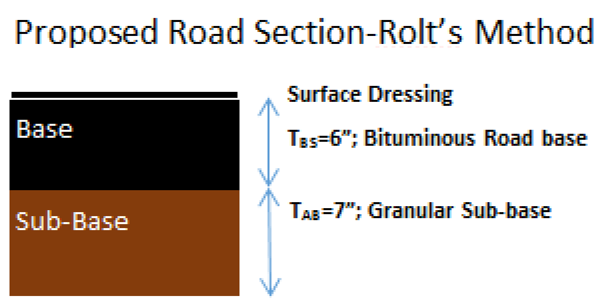


Figure 54: Proposed road section for CSAH 14 using Rolt's method

Russell’s method

ESALs (In one direction) = $0.367 \times 10^6/2 = 0.1835 \times 10^6$

CBR (%) = 13(CSAH 14-AASHTO Method using nomographs)

Proposed Road Section-Russell's Method

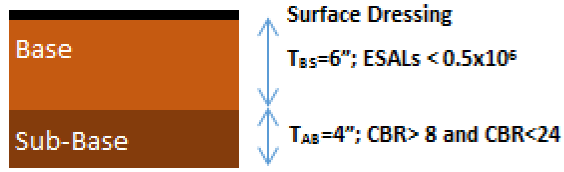


Figure 55: Proposed road section for CSAH 14 using Russell's method

<u>CSAH 10</u>

Rolt's method

Chart 7

ESALs= 234,000(Figure 47)

Traffic classes= T1

CBR (%) = 10(CSAH 10-AASHTO Method using nomographs)

Sub grade strength classes= S4

There is no road design that falls within this quadrant (Figure 52). As a result, the design method with the least structure required for a road with a sub grade class of S4 is selected.

Proposed Road Section-Rolt's Method

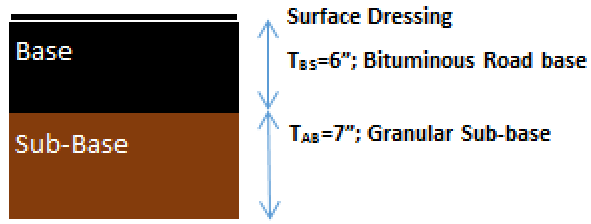


Figure 56: Proposed road section for CSAH 10 using Rolt's method

ESALs (In one direction) = $0.234 \times 10^6/2 = 0.17 \times 10^6$

CBR (%) = 10(CSAH 10-AASHTO Method using nomographs)

Proposed Road Section-Russell's Method

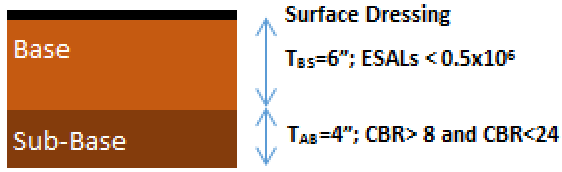


Figure 57: Proposed road section for CSAH 10 using Russell's method

Both of these methods have been established to design roads that would be built with a light surface treatment. However, neither of these methods considers a SFDR as a road base option. Additionally, both of these methods only consider the heavy traffic ESALs and the structural strength of the road as factors towards designing roads. There are factors such as the climate and cost of implementation that could be considered in the model. Another limitation is that these models do not consider the existing layers. Additionally, these methods were not developed to specifically design low-volume roads. This is evident due to the number of ESALs considered in each model.

The total depth for the road base and sub-base of CSAH 14 and CSAH 10 are 13.5" and 11" respectively. Rolt's and Russell's method suggested that the total road base and sub-base are 13" and 10". Rolt's and Russell's methods produced the same designs for CSAH 14 as for CSAH 10. The difference in ESALs on both of these roads is 1.3x10^5 and the soil conditions of the counties are quite similar. Within the design methods used in the United States, an increase of 1.3x10^5 ESALs could change the design by up to 3".

The results developed by Rolt's and Russell's method are similar to the designs found by the methods used in the United States. For CSAH 14, there is a 2" difference in the road base thicknesses between the designs by Rolt's method and the designs produced by the GE method. Rolt's method produced a design that is 3" thinner than the design produced by the

AASHTO method. The design produced by Russell's method for CSAH 14 provided less structural strength than any of the methods used in Minnesota. For CSAH 10, Rolt's method provided 2 inches of additional road base thickness in comparison to the design methods used by local road officials in the United States. Russell's method produced a design similar to the Mechanistic Empirical method and the GE method.

Analysis

ESALs

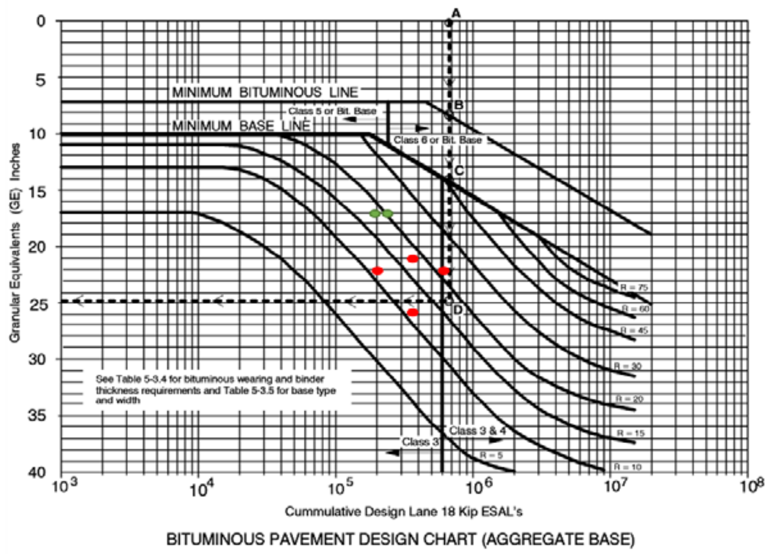
The selection of the heavy traffic ESALs and the soil conditions have a noticeable impact on the design. During the design of CSAH 14, the ESAL calculator determined that the heavy traffic ESALs on the road would be 367,000, but the low-volume road officials estimated the heavy traffic ESALs to be 200,000. If the GE method using the pavement design chart is chosen as the design method for the SFDR, selecting 367,000 ESALs instead of 200,000 would result in an increase of an SFDR depth of 8". For the Mechanistic-Empirical method and the AASHTO Method, selecting 367,000 ESALs instead of 200,000 ESALs would increase the SFDR depth up to 4".

During the design of CSAH 10, the ESAL calculator generated a heavy commercial percentage of 9.45 percent based on the AADT and location of the road. However, the plans show a heavy commercial percentage of 4 percent. When the values of 9.45 and 4 percent are entered into the ESAL calculator, the ESAL values generated are 551,000 and 234,000 respectively. If the GE method using the pavement design chart is chosen as the design method for the SFDR, selecting 551,000 ESALs instead of 234,000 would result in an increase of an SFDR depth of 10”. For the Mechanistic-Empirical method, the difference in ESALs would result in an increase of 5” and for the AASSHTO method the difference in ESAL values would result in an increase of 1” for the SFDR layer.

The results show that amongst the three design methods, designs produced by the AASHTO method changed the least as a result of the change of ESALs. The axis of the ESALs on the nomograph is labeled in such a way that an increase of ESALs does not particularly impact the design. Designs produced by the GE Method using the pavement design chart changed the most as a result of an increase of ESALs. The R-Value curves on the pavement design chart change from a straight line to a curve at some point after 10,000 ESALs. As a result, the ESALs have a very noticeable effect on the design.

R-Value or Soil Conditions

Table 22shows that if the GE Method using the pavement design chart is selected as the design method, decreasing the R-Value from 18 to 11 results in the addition of 10 inches of SFDR depth. However, if the AASHTO method is chosen and the R-Value was decreased from 18 to 11 that would only require a 2” increase in the SFDR. The R-Value for the sub grade of CSAH 10 is shown in the plans as 20. Since this seems to indicate more certainty with regards to the R-value, there was no comparison made amongst various R-Values for the Goodhue County case study.



Design thickness of FDR is less than existing road thickness

Design thickness of FDR is more than existing road thickness

Figure 58: GE values that require a SFDR that exceed the thickness of the existing road

Figure 58 shows the points on the pavement design chart of all the designs conducted during this research project using this particular design method. The points highlighted in green would produce designs that would require an SFDR less than the total thickness of the road. The red points produced designs that would require that additional aggregate, placed on top of the road, would have to be used in the SFDR process. All the red points also produced designs that required a SFDR greater than 12”. From a constructability and cost standpoint, constructing an SFDR layer with thicknesses greater than 12” is difficult (Johnson T. , 2013).

Road Designs

The case studies show that the Minnesota GE Method using the pavement design chart is the most conservative design method for the road structure of an LST. The case studies show that this method noticeably increases the amount of required road structure if the assumed ESAL value is high or the sub grade R-Value is low. If the ESAL Value is relatively low and the R-value is relatively high then this GE Method tends to provide designs similar to the other methods.

The 9-ton GE Method provides designs that are more conservative than the 10-ton GE method if the AADT is less than 1000. This is because the 9-ton chart uses 150 HCAADT to design low-volume roads. 150 HCAADT will produce designs considered to be conservative since many rural roads in Minnesota will typically have less than 150 HCAADT. The 10-ton chart differentiates between roads with less than 1000 AADT and roads with less than 150 HCAADT. If the road has an AADT above 1000, then the 10-ton chart will provide a more conservative road design.

For CSAH 14 and CSAH 10 the Mechanistic-Empirical method tends to provide road designs with the least SFDR depth required. In both case studies, the required SFDR depths of 5 inches (CSAH 14) and 1 inch (CSAH 10) were the lowest.

THE AASHTO method tends to produce designs that require depths that are within the range of the depths required by the GE method and Mechanistic-Empirical method. The results show that the AASHTO method, compared to other methods seems to be relatively insensitive to changes in the R-Value. If the R-Value is decreased from 18 to 11 the road design for CSAH 14 using the AASHTO method increases the SFDR depth by 2. There is a 1 inch difference between the two road designs executed for CSAH 10.

Both case studies produced designs that recommend constructing a stabilized full-depth reclamation layer at a depth that exceeds the combined depth of the bituminous surface and aggregate base. For example, the 10-ton design using the GE method chart recommends an

SFDR of 14” if CSAH 10 has 551,000 heavy traffic ESALs over a 20-year life. The existing road structure of CSAH 10 has 7” of existing bituminous, 4” of class 3 and 8” of select granular. The calculations recommend replacing 3” of the select granular material with the SFDR. According to the calculations, this design would provide sufficient structure but it would be impractical to build. A contractor (Johnson T. , 2013)who operates within the state of Minnesota area suggested that 12inchesis the maximum depth that an SFDR should be attempted.

Even though Rolt’s and Russell’s methods have been established to design roads with LSTs, there are still shortcomings to be addressed when designing lightly surfaced roads in developed countries.

Limitations of each method

The most important limitation of the GE Method (9-ton and 10-ton tables using soil factors) is that the design is based on the highest amount of traffic considered in each category. CSAH 14 has an AADT of 450 but this method required the author to design the road to 1000 AADT (10-ton) and 150 HCAADT (9-Ton). As a result, the designs provide more strength than required.

The limitation for the GE design chart method is that it requires converting the Soil factor to an R-Value. Table 10 can provide an approximate conversion but the R-value noticeably affects the design so the precision of the R-value is important.

The main limitation of the Mechanistic-Empirical method is that the MnPave software requires that the user places a minimum of 1” of HMA in the design. This layer provides additional support that would not exist if the SFDR was built with a light surface treatment as a surface course. This limitation can be changed within the software by MN/DOT staff. If the users use the software as it appears in this research, material that has an equivalent GE value can be substituted for the 1" HMA layer.

One limitation to the AASHTO method is the user must make an assumption for a value of the structural coefficient of an SFDR. Each layer within a road structure is assigned a structural coefficient but the table referenced in the research does not provide a structural coefficient for the SFDR. Also, there are more charts and conversions throughout the AASHTO method than any other method. There is a higher chance for lower precision in the design process if there is a high number of charts and unit conversions.

Recommendations

When designers select the number of heavy commercial ESALs to use for the design of a road, the author recommends using the ESAL calculator provided by MN/DOT. The ESAL calculator can calculate the heavy commercial ESALs either by using the actual percentage of heavy commercial traffic or a pre-determined percentage estimated by the software. The author recommends using the actual percentage of heavy commercial traffic. The percentage of the various truck types should be estimated as shown in Table 19.

If the heavy commercial AADT of the road is not available, then the ESAL value that is generated by the ESAL calculator software can be used for the design. If the user does not have access to the ESAL calculator, the user can also use hand calculations to find the ESAL.

An example on how to calculate the ESALs is shown below:

1. **Find HCAADT(if provided in specification continue to step 2)**

AADT* Heavy Commercial %= HCAADT

2. **<u>Multiply HCAADT by Flexible Factor</u>**

HCAADT*Flexible factor

150*0.4(Assumption) =60

3. **<u>Find ESALs over the life of the road</u>**

60*365=21,900

20-Year Life

21,900*20=**<u>438,000</u>**

If the R-Value of the sub grade of case study is not available, the author recommends using the average R-Value generated by the FWD analysis tool. If FWD data is not available, Table 10 can be used to convert the soil classifications to an R-Value.

Design method selection

The method that is most straight forward to implement is the GE method. The GE method using soil factors allows the user to choose a table based on the AADT and HCAADT values found on the road. The tables used to identify the total required GE for the road are categorized based on ranges of AADT. The majority of roads considered LVRs will have an HCAADT less than 150. Therefore, selecting the appropriate table is a relatively easy step. The other input used in this design method is the soil factor. Typically low-volume road officials select soil factors based on their judgment and experience. The GE method using the pavement design charts requires that the user selects an ESAL value on the road over a 20-year design life and the R-Value of the soil. Based on the results that were found in this study, these charts seem to work best if the total required GE value is relatively low (Figure 58).

The Mechanistic-Empirical method requires the most input factors and the most information to develop road designs (Table 24). The options offered within the MnPave software allow the user to easily try several designs in an iterative fashion. This method would be recommended to users that would like to evaluate various road designs before selecting which road design to build. The software can be used to do a cost analysis or a life cycle analysis as well.

When selecting a design method it is important to consider the AASHTO method as the least sensitive to the ESAL number.

Table 24: Table to show the inputs required for each design method

Input Values	GE Method using soil factors	GE Method using R-value	AASHTO method (Nomograph)	Mechanistic-Empirical (MnPave)
Soil	Soil Factors	R-Value	CBR %	R-value/ AASHTO/ MN/DOT
Traffic Levels	AADT and HCAADT	ESALs	ESALs	ESALs
Climate	N/A	N/A	Regional	Regional
Statistical Analysis	N/A	N/A	N/A	Monte Carlo
Material Options	Various Options	Various Options	Various Options*	Most Options

*SFDR is not available as a base option

Conclusion

This research found that the Granular Equivalence (GE) method, the Mechanistic-Empirical (M-E) method, and the AASHTO can be improved to better design road structures built to support light surface treatments. The GE Method using soil factors requires a 3” bituminous layer to be included in the road design. The Mechanistic Empirical method using the MnPave software requires a minimum of 1” of HMA within the road design. These design methods produce road designs with the assumption that a bituminous layer will be placed on the road base. These road design methods are being used even though a bituminous layer will not be applied to these roads. The main shortcomings of the AASHTO method using nomographs is that it does not define a structural coefficient for an SFDR and there are a high number of charts which could lead to the user committing errors.

Throughout the United States, a majority of local officials are using pavement design methods that are intended for standard pavement design situations to design low-volume roads that are surfaced with an LST (Hall & Bettis, 2000). The author recommends that agencies conduct an analysis similar to the one conducted in this research to find the shortcomings of the design methods that are used in their jurisdictions. The improvement of the design methods will provide a higher probability that the roads will be built economically and be designed with sufficient structure to reach the intended life expectancy. When the GE Method and the AASHTO method were designed, the cost of asphalt was not as much of a concern as it is now. Consequently, these are design methods that are likely to recommend thick layers of pavement. The M-E method is a relatively modern design method but the software often associated with this method is not as straightforward to use as the GE and AASHTO methods.

There is a need for a design method that is both modern and practical enough to be used by low-volume road officials.

Features to be considered in this design method include a minimum acceptable thickness for road bases and a maximum thickness for an SFDR. The design method should include the climate as a factor which affects the design. Another useful feature would be to provide a wide range of material selections to include as a base or sub-base. Examples of such layers are SFDRs and Cold in Place Recycling. It is important for a new design method to consider the existing road base as well as the sub grade conditions. Lastly, if the design method is established for low-volume roads then the charts should only include ESAL values expected on low-volume roads. All of the design methods reviewed in this study applied to roads with more than one million ESALs of heavy traffic; one million ESALs is an unlikely traffic level for a low-volume road.

CHAPTER 4

GENERAL CONCLUSION

The increasing demand for paved roads, the increasing cost of asphalt paving and the limited revenues available to low-volume road officials are causing these officials to consider an alternative to the currently typical low-volume road pavement designs. One alternative is to prepare a base and/or sub-base to withstand the traffic loads and apply a light surface treatment as a surface course. The successful implementation of light surface treatments on aggregate-surfaced roads or recycled pavements could provide noticeable cost savings to low-volume road officials. The selection of a good candidate road and the design of the road structure of an LST are important factors towards building roads that will not fail before their expected life. There are a number of selection guides and design methods for LSTs that have been established, but they apply mainly to developing countries. During the case study research, it was found that the low-volume road officials in Minnesota do not use a formal process to select candidate roads and they use pavement design methods to design the road structure of LSTs. According to our findings and a study published by (Hall & Bettis, 2000), this is a trend throughout the United States.

This research effort develops an improved process for candidate road selection and discusses the features to be included in a design method for the road structure of an LST. The selection guide consists of a GIS model to conduct a preliminary analysis of the road features and a decision process to follow during a site investigation. The current design methods used by local road officials to design the road structure of LSTs are pavement design methods. The pavement design methods used in Minnesota are the Granular Equivalence Method (GE Method), the Mechanistic-Empirical method, and the AASHTO method. These pavement designs all have shortcomings when used to design roads for LSTs. This report outlines these shortcomings and proposes features that could improve these design methods for use with LSTs in the United States.

The current practices were established during a time when asphalt paving was relatively low priced compared to current prices and thicker asphalt layers were routinely designed. Since this is no longer the case, design methods that are more applicable for LSTs should be developed and implemented.

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Pinard, I. M. (2011). *Performance Review of Design Standard and Technical Specifications of Low-volume roads in Malawi.* Gaborone, Botswana: African Community Access Programme(AFCAP).

Rolt, J., Smith, H., Toole, & Jones, C. R. (1993). A guide to the structural design of bitumen-surfaced roads in tropical and sub-tropical countries. *Transport Research Laboratory,Crothorne, Berkshire, United Kingdom*, 76.

Russel, & Hitch. (1977). Bituminous bases and surfacings for low-cost roads in the tropics. *Transport and Road Research Laboratory,Crowthorne, Berkshire, England*.

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UKDFT. (2011). *Thin Surface Course Systems-Installation and Maintenance.* UK Department for Transportation.

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Yamada, A. (1999, April). *Asphalt Seal-Coat Treatments*. Retrieved May 2013, from Us Forest Services: http://www.fs.fed.us/eng/pubs/html/99771201/99771201.htm#SLURRY

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Yin, R. (1994). *Case Study Research-Design and Methods-Applied social research methods series, v5.* Thousand Oaks, California: Sage.

APPENDIX A

COST OF LIGHT SURFACE TREATMENTS

	Construction Cost	Yearly Maintenance Cost	Expected Life* (years)	Major Maintenance	Frequency of Major Maintenance**	15 Year Cost
Double Otta Seal	$40,810	$1000	12-16 (NPRA 2007)	$40,810	2	$137,432
Double Chip Seal	$37,733	$1000	7-10 (NPRA 2007)	$33,226	2	$141,720
Slurry Seal	$32,384	$1000	2-6 (NPRA 2007)	$32,384	3	$144,536
Cape Seal	$70,400	$1000	8-10 (NPRA 2007)	$70,400	1	$151,576
Sand Seal	$21,718	$1000	2-4 (NPRA 2007)	$21,718	4	$123,592
Soybean Soap Stock	$56,320	$1000	1-2 (US ROADS 1998)	$56,320	6	$409,240
Asphalt Paving * **	251,959	$2,338	15	0	0	287,029

*Expected Life References:

Overby, C., Pinard, M. (2007).*The Otta Seal Surfacing-An economic and practical alternative to traditional bituminous surface treatments*. World Bank, Norwegian Public Roads Administration (NORAD), Norway.

Overby, Charles. (1999). *A Guide to the Use of Otta Seals*. World Bank, Norwegian Public Roads Administration (NORAD), Directorate of Public Roads, Road Technology Department International Division, Oslo, Norway, Publication Number 93, pp. 7-15.

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**This number can vary based on the means and methods toward building the light surface treatment.

*** The data for these costs is obtained by a study conducted by North Branch, Minnesota. The construction costs assume that the Wear Course Mix costs $46.84/ton and that the application rate is 140lb/cuft.

APPENDIX B

COUNTY MAP OF MINNESOTA

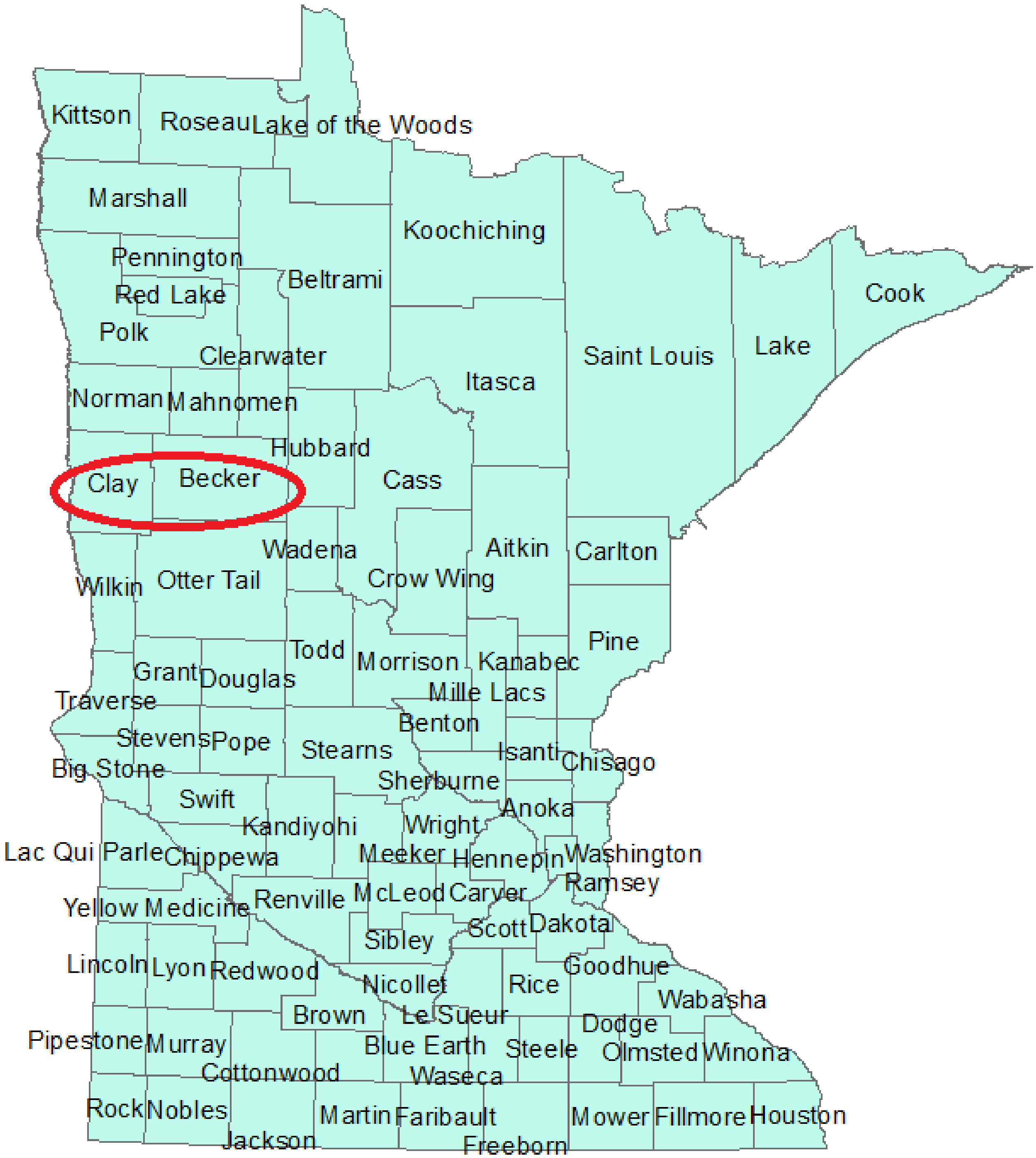


Diagram by Francis O. Dayamba

APPENDIX C

SURVEY DISTRIBUTED TO COUNTY ENGINEERS IN MINNESOTA

Light surface treatment (LST) LRRB Informational Survey

The purpose of this survey is to gather information about the light surface treatments that have been implemented in counties in Minnesota. Once the information from this survey is collected, it will be followed by a 20-30 min phone interview to discuss the implementation of the treatments. The follow-up interview will include questions that discuss topics such as road conditions, traffic type, methods of application and the performance of the light surface treatment. An agenda of the phone interview will be sent out prior to the interview. The interview will be most beneficial to the research group if the survey respondents are able to gather the answers to our questions before the scheduled interview. The survey is to be filled out by anyone with in-depth knowledge of the implementation of the light surface treatment in the specific county.

1. Name: 2.Today's Date: 3.Phone Number:
4. County or Township and State: 5.E-mail:

6. Check the Light Surface Treatments that your county has applied on low volume rural roads

Treatments	Otta Seal	Double Otta Seal	Chip Seal	Double Chip Seal	Oil Gravel	Other(Specify):
Number of times applied						

7. Provide the following details for the examples listed in question 6. Limit your response to three roads. Only include roads that have been available for use to the public since 2010.

	Road Name and Location	LST segment length	What year were the LST applied
1			
2			

8. Has your county applied Light Surface Treatments on more than 3 roads? Yes No

9. Please specify 3 time slots when you would be available to conduct the 20-30 minute phone interview. The research team is not available from January 12th-17th

10. Comments/Concern

APPENDIX D

INTERVIEW WITH COUNTY ENGINEERS WHO HAVE BUILT LIGHT SURFACE TREATMENTS

Name: State: Phone Number:
County or Township: Today's Date: E-mail:

1. Circle one treatment that you have applied on an aggregate-surfaced road:
Otta Seal Double Otta Seal Chip Seal Double Chip Seal Oil Gravel Other(Specify):

Choose a road to discuss in detail that was paved in 2010 or earlier

2.In what month and year was the LST applied on the road?

3.Road Name:

4.Road Location:

5.LST segment length and Road width:

6.Describe Traffic type, median road speed and provide ADT of road:

7.What work did your crew do in order to prep the base for construction?

8a.Was the treatment a **Success** or **Failure**? Discuss your answer.

8b.What are the benefits/Disadvantages of the LST?

9.What type of aggregate was used(Include size, shape)? Was the aggregate obtained from a local source?

10.Road Condition after LST(Circle Answers which best apply)
a. Thermal cracks: Severe Minimal None
b. Rutting: Severe Minimal None
c. Is Maintenance needed? : Major Minor(Patchwork) None required;
d. Has maintenance been applied on the road(If yes, please describe): Yes No

11.Cost per Mile of LST(Use the most recent cost data available):

Construction Costs of LST

Construction Costs of LST	Cost
Oil Emulsion	
Aggregate	
Labor/Equipment	
Base Stabilizer and Gravel	
Other Cost(specify)	
Other Cost(specify)	
Total Construction Cost	

Maintenance Costs of LST

Maintenance Costs	Cost
Minor(i.e. Patching)/ year	
*Major	

*How often do you expect that major maintenance is required?

12.Application Details:

- Application rate of Binder/Prime on Base
- Equipment used to spread aggregate
- Was a pneumatic roller used?

13.Describe Each Layer of the road: include the existing condition/material/thickness

- Spray applied on Surface(i.e. Dust Coat/Fog Seal)
- Surface
- Base(Was a stabilizer applied)
- Sub-Base
- Sub-grade

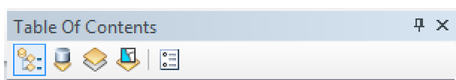
14.Did you use any specifications for the Light Surface Treatments?

APPRENDIX E

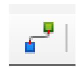
GENERAL GIS BASIC INFORMATION

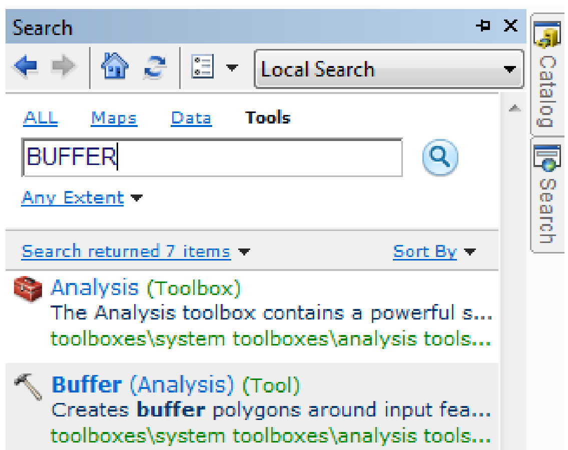
The first step is to open ARC Map 10.1 and at this point a window will pop-up (getting started window) asking if the user would like to begin the model with their template. Close this window and begin by creating a geodatabase to work with for the project.

The Table of Contents (TOC) is located to the left of the screen and Catalog is located to the right of the screen. Throughout the GIS map both the TOC and Catalog will be refereed to frequently. It is important that the user knows where they are located.



Create a Model:

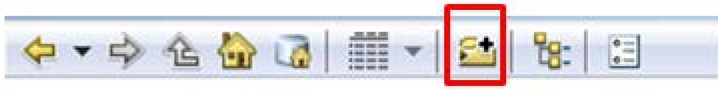
It is useful to create models because the user can track all the steps that have been taken with the Geoprocessing Tools included in the model. In order to create a model the user should Right-click on the geodatabase and click New and select Toolbox. At this point the user should name the Toolbox. Right click on the toolbox and click New and then select Model. Once the model appears, click Model, Save As and Name the model. All the files that are used in the model can either be dragged with the mouse or uploaded (typically color blue). The geoprocessing tools can also be dragged into model. A simplified way to find a geoprocessing tool is to use the search toolbar (Left-click Windows and Search). Within the Search toolbar, select tools. Once the tool appears in the search toolbar (as shown below) it can be dragged into the model. An additional feature is that if the user clicks on the links below the tools, ARCGIS provides examples of how the tool can be applied. Once the user is able to drag all the files into the model, the user can connect them by using the  connect button. Once all the shapefiles are connecting, the user can select the check to validate the model and select the blue triangle to run the model. . Also, it is useful to select the Auto Lay-out button to show the model in a lay-out that is easier to understand. Once the model is run, if a shadow appears under the shapefile then that file was considered in the run. If there is no shadow underneath the file then that is an indication to open this shapefile and begin troubleshooting.



Whenever the user is to create a shapefile in a model (green), the file can be added to the Table of Contents by right clicking the file and selecting “Add to Display”

Create a Geodatabase:

In the top toolbar select Windows, Catalog. Hit the folder connections button and scroll to the folder in which the user saved all the data.



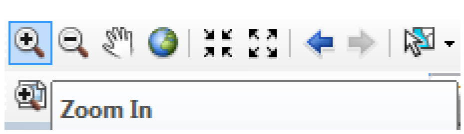
Right Click on the folder, click New and Create a New File Geodatabase. At this point the user can change the name of the file geodatabase to name that will help the user identify the type of data that will be assembled for this project.

Set Default Geodatabase and store pathnames to data sources:

Then it is advised to set a default geodatabase and store pathnames to data sources. In order to do this, select File, Map Document Properties, scroll to the bottom of the pop-up window and select the folder that is to the right of the Default Geodatabase. Open this folder, click on the geodatabase that the user created and click add. Then check the button store relative pathnames to data sources. These processes will ensure that all the created shapefiles will be created in the geodatabase and that the pathnames will be stored. So if the user is to use a different computer, ARCGIS will still know where the files are located.

Once the user creates a geodatabase, the user should add the shapefiles that were downloaded by using the Add Data  button.

Create and Export Maps

In order to create maps, scroll to the top of the screen and select View, Lay-out View. Once in Lay-out view be sure to include a Scale, a legend a Title and a North Area. The contents of the Legend can be adjusted by right clicking on the legend. (Note: a useful feature when creating a map is 

the Zoom In and Zoom Out buttons. If the user clicks the Zoom in Button, they should then place a box over the model and it will zoom in to show that box.

There are shapefile layers (muni.shp) that when added to the Table of Contents does not appear on the map because it has not been assigned a coordinate system. In order to assign a coordinate system to a layer, the user must find the layer in the catalog and right-click the layer. Select properties and click the XY Coordinate System. Once this is selected the user can assign the appropriate coordinate system to the file. For the muni shapefile example, the user should select Projected Coordinate Systems, UTM, NAD 1983, and NAD 1983 UTM Zone 15N.

Select by Attributes

In order to proceed with a select by attributes the user should begin by clicking select on the main toolbar, followed by select by attribute.

Double click on the field that user wants to query

Click "Get Unique Values". This will create a list of all the values that can be selected in this field.

In the white box, the user can type (in equation form) what the user would like to be selected. All the operators that are not familiar are listed below:

Like Similar to equal operator but used for character or string data and allows for wildcards

Not-excludes values. Is usually used with the And operator.

And-Both expressions are true.

Or-At least one expression is true

Is

<>-Not equal to

Wildcards are used to select subsets of a text string. Usually used with Like.

Wildcard Spaceholders

_-Wildcard

?-Wildcard

Wildcards that select everything

%-Wildcard-

*-Wildcard-This wildcard operator replaces more than one number/string

If the user is interested in the full list of operators or more information on wildcards, refer to the following website

www.junipergis.com "Selecting Features by Attributes in ARCGIS"

APPENDIX F

COUNTY GIS MAP-MODEL IN ARCGIS

Highlight all unpaved roads with an AADT between 200- 500 and are not located within a municipality

Download the county boundaries data of the state of Minnesota and use the  Add data button to add the shapefile Note: the map may not appear.

Find the shapefile in Catalog, right click on the file and select properties. Note: If the user cannot find the shapefile, refresh the folder where the user saved it. This is because user must assign the correct coordinate system to the file. Click the XY Coordinate System tab and click the following folders: Projected Coordinate Systems, UTM, NAD 1983 and click the coordinate system NAD 1983 UTM Zone 15N

Then the user needs to select Becker/Clay County. There are a number of ways to make this selection. One way is to right click on the county shapefile, click selection and make the shapefile the only selectable layer.

Then click the  select features button and click on Becker County.

Right click on the county shapefile, click selection and click Create Layer from Selected Featured features.

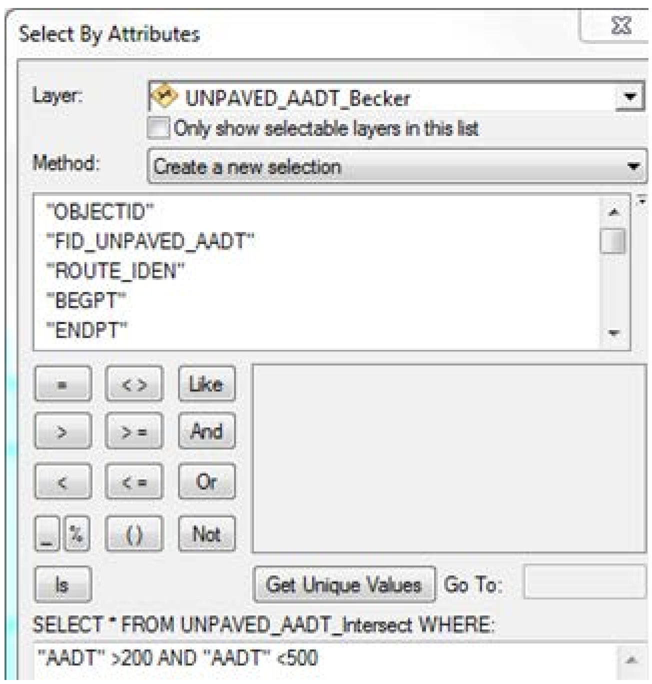
Change the name of the layer to Becker County

Download the Unpaved AADT data

Select all the unpaved roads in Becker County.

Add Unpaved AADT to the map of Minnesota. Use the geoprocessing intersect tool, to find the unpaved roads in Becker County. Click geoprocessing tool, intersect. For the Input features select Unpaved_AADT and Becker County, for the Output Feature Class save the file to the geodatabase and change the name of the file.

Click Select, Select by Attributes and enter the following information as shown in the image below



Download the municipality data to find which roads are within a municipality and erase these roads.

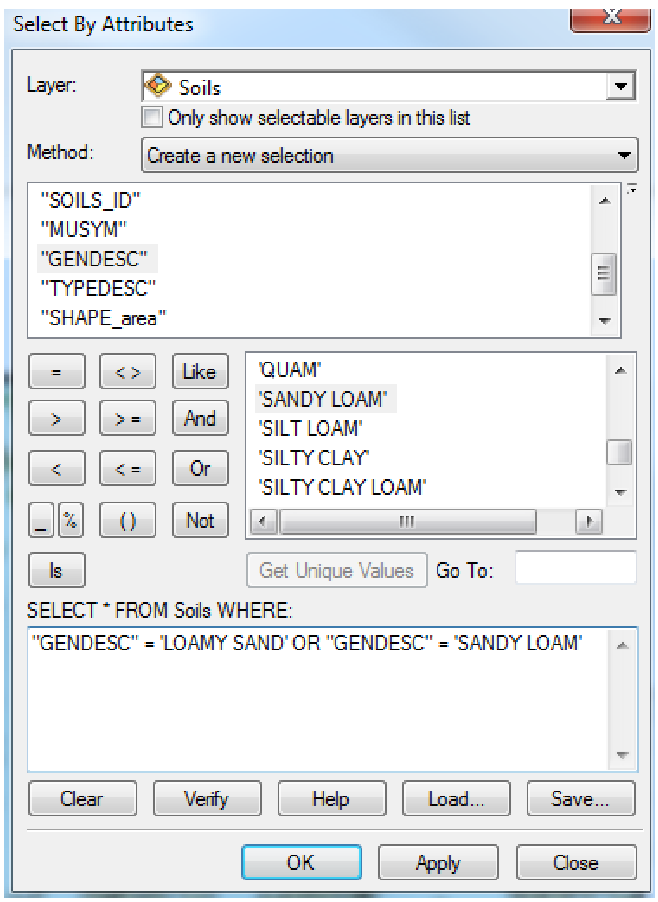
Click the geoprocessing (in the main toolbar) and click intersect. As the input features use the municipality shapefile and unpaved paved roads in Becker County. Click Ok. This should highlight all the unpaved roads within a municipality

Search a geoprocessing tool called Erase; enter the unpaved AADT in the range of 200-500 as the input feature and the unpaved roads within a municipality as the erase feature.

Highlight soil types that are likely to successfully support an LST

Download the soil zip folder and add the soil shapefile into the data

On the toolbar, click selection, "Select by Attributes", and enter the information as shown in the screenshot below. In the select window, the following information is entered. Select GENDESC="Sandy Loam" OR GENDESC="Loamy Sand".



Right-Click the layer in the Table of Contents and Select "Properties". Select General tab, name the layer appropriately and click Ok.

Change the color of this layer by selecting the color that is found below the layer name in the Table of Contents.

Follow the same process but instead select “Clay”

Once the clay soils are selected, choose a different color for the clay soil.

Highlight all areas that will not typically carry heavy agricultural traffic

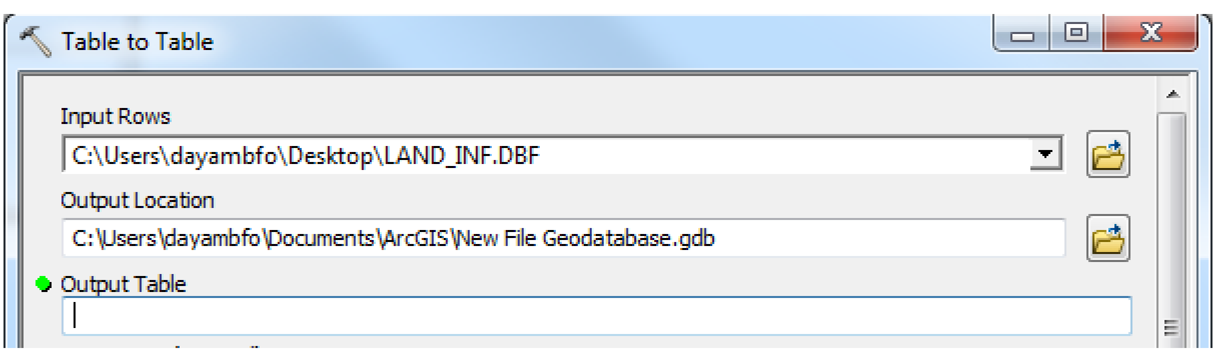
Download the parcel zip file and the Becker parcel Microsoft access file save in folder

Add the parcel shapefile to the ARCGIS map using the  Add Data button located in the top toolbar.

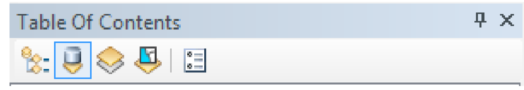
Open Becker parcel Microsoft access file and right-click on the table with land use data (Land_Info)

Export the file as a dBASE file and save into folder

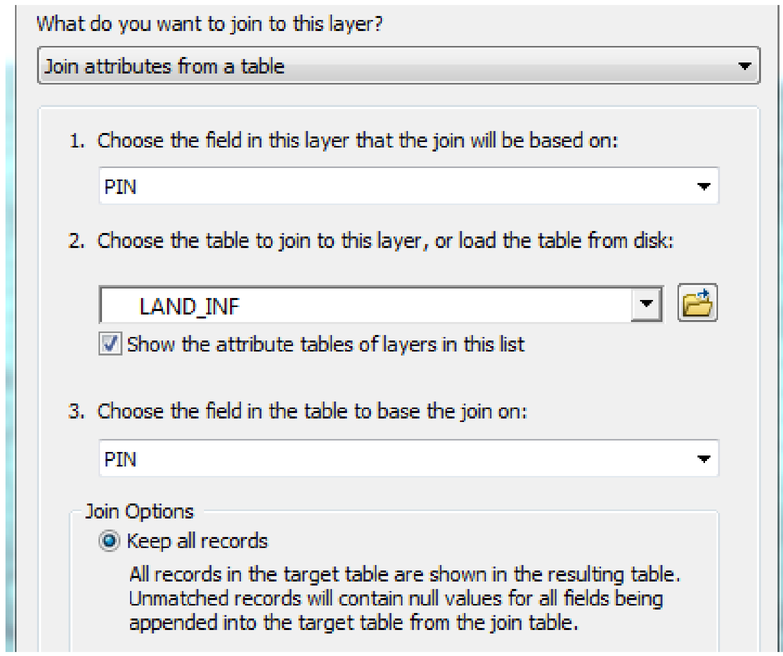
Import the dBASE file into the geodatabase by right-clicking on the geodatabase in Arc Catalog, click import and click Table (single)



Enter the Output Location (geodatabase) and Output value (name that describes data) and click Ok

In the Table of Contents, click the List by Source button 

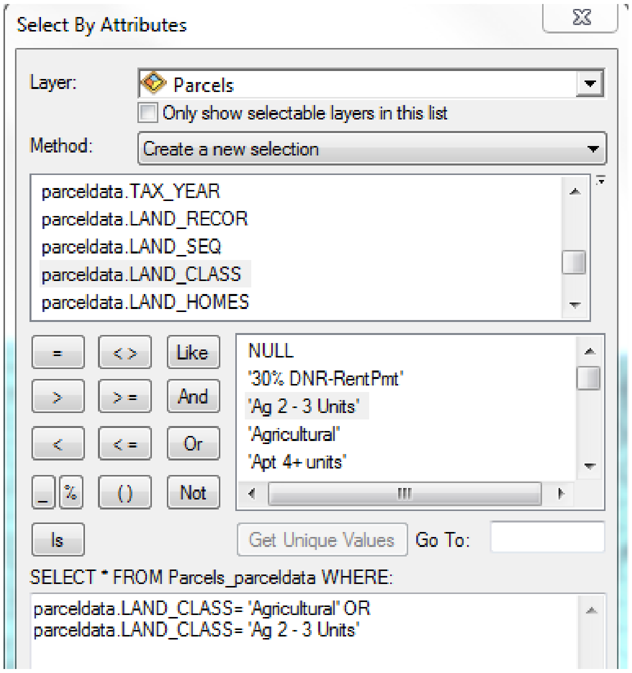
Right-click on the Parcel shapefile, click Join and Relate and click Join



And validate the join before clicking Ok.

Click Selection on the main Toolbar, and select by attributes.

Enter the information as shown below, verify the records and click Ok. Note: Once the user clicks on parceldata.LAND_CLASS select Get Unique values and all the various values in that column will appear. If there are other Land classifications that might be indicative of an agricultural parcel then they can be included.



Right click on the parcel shapefile, Selection and Create Layer from Selected Features

Change the name of the selection by right clicking parcel, clicking properties, and clicking the general tab.

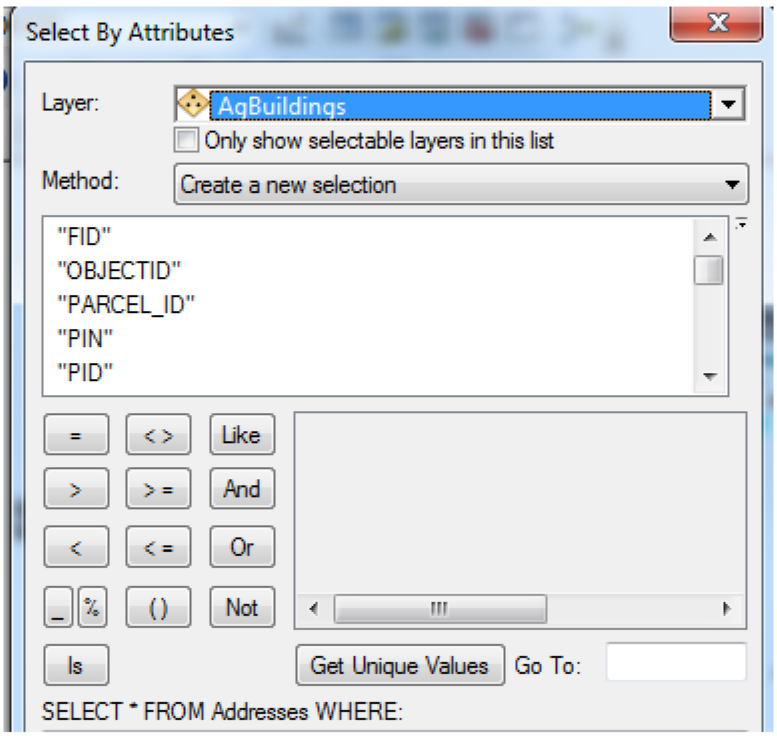
Differentiate between Agricultural parcels likely to attract heavy traffic or light traffic

In order to differentiate between these buildings the author conducted a “select by attributes” to find the data. This requires the user to read through the various descriptions and identify all the buildings that they believe would attract heavy or light traffic. In this particular example, the author decided that buildings with the descriptions below would attract heavy traffic:

- Bins
- Construction
- Backhoe Service
- Fruit Farm

- Garage
- Gravel Pit
- Livestock sheds
- Parking Area

In order to search the data to find buildings with heavier traffic, scroll to the main toolbar and click select and select by attributes. Proceed to choose the layer and the field with the descriptions as shown in the screen caption below.



Then click the "Get Unique Values" button and this will provide the user with all the descriptions available in the data. If there is a description that the user believes will attract heavier traffic, click the appropriate field, the "like" operator and the appropriate description. An example is shown below for the descriptions of backhoe service, fruit farm and garage.

```
"COMMENTS"= 'BACKHOE SERVICE' OR "COMMENTS"= 'FRUIT
FARM' OR "COMMENTS"= 'GARAGE'
```

If the word is not a unique value (i.e. there is one word within a description that might attract heavier traffic) the word should have the percentage operator followed by the single quotations. An example is shown for bin, construction and farm.

```
"COMMENTS" LIKE '%BIN%' OR "COMMENTS" LIKE
'%CONSTRUCTION%' OR "COMMENTS" LIKE '%FARM'
```

APPENDIX G

STATE GIS MAP-MODEL IN ARCGIS

Highlight all aggregate Sources

Identify active aggregate pits (M, O), rock quarries (Q) and commercial aggregate(C) in the state of Minnesota. Click Select (main toolbar) and select by attributes.

Choose the layer with the aggregate sources (ASIS), click the status field and enter the information as it appears in the image below and click Ok.

```
"STATUS"= 'M' OR 'O'
```

Right click on the shapefile, click selection, Create Layer from Selected Features

Follow the same steps twice and create separate layers for Q and C.

Highlight all unpaved roads with an AADT between 200- 500 and are not located within a municipality

Add Unpaved AADT to the map of Minnesota.

Click Select, Select by Attributes and enter the following information as shown in the image below

Download the municipality data to find which roads are within a municipality and erase these roads.

Click the geoprocessing (in the main toolbar) and click intersect. As the input features use the municipality shapefile and unpaved paved roads in Becker County. Click Ok. This should highlight all the unpaved roads within a municipality.

Search a geoprocessing tool called Erase; enter the unpaved AADT in the range of 200-500 as the input feature and the unpaved roads within a municipality as the erase feature.

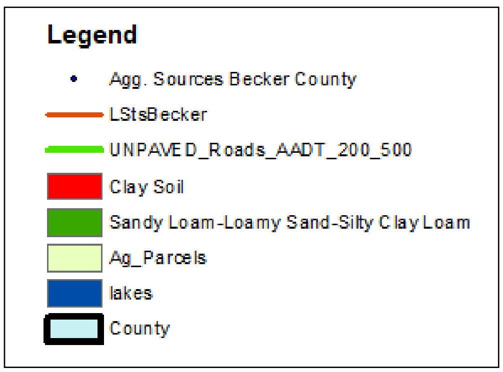
Table 25: To show the various aggregate sources outlined in the GIS data on a county-leve lhttp://www.dot.state.mn.us/materials/maps/copitmaps/Agglegend.pdf(Accessed July 2013)

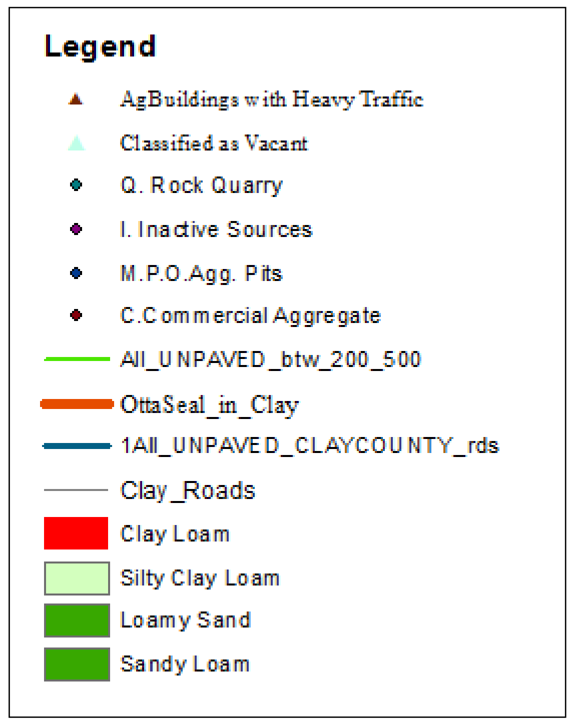
	Aggregate Source	Description
P	Aggregate(Prospected)	Indicates a pit that has been prospected and/or leased by MN/DOT. A "**P**" classification does not necessarily imply that the source is actually producing aggregate at the present time. In fact, it may only indicate an aggregate deposit that was at one time leased by MN/DOT and that the Aggregate Unit has tested, but from which no material has ever been excavated.
M	Aggregate Pit-MN/DOT	Indicates an aggregate source that is owned and managed by the Minnesota Department of Transportation (MN/DOT).
Q	Rock Quarry	Indicates a bedrock quarry. Rock type depends on area geology, but most are limestone/dolostone and are located in Southeastern Minnesota.
C	Commercial Aggregate	Indicates an identified commercial source of aggregate that has been assigned a source number in order to facilitate tracking of test results when the source is used on MN/DOT or county projects.
O	Aggregate (other)	Indicates other aggregate pit locations assigned a number in order to facilitate tracking of test results.
I	Inactive Aggregate Source	Indicates a source that is either depleted or at least unavailable for future use. (If future circumstances make such sources available, the status may be changed).

APPENDIX H

LEGENDS FOR

Figure 10AND Figure





APPENDIX I

CASE STUDY ROADS WITH LIGHT SURFACE TREATMENTS IN BECKER COUNTY

1. Golf Course Road

2. West Common Road

3. CO 147

4. Deroxe Road

5. Schurman Drive

6. North Pearl Lake Road

APPENDIX J

ROADS WITH LIGHT SURFACE TREATMENTS IN CLAY COUNTY

County Road 95

APPENDIX K

USING GIS MODEL AND SITE INVESTIGATION TO DETERMINE WHETHER THE CASE STUDY ROADS ARE CANDIDATE ROADS FOR AN LST

GIS Files							
	Becker County						Clay County
	1	2	3	4	5	6	7
Case Study roads	Golf Course Rd	West Common Road	CO 147	Deroxe Road	Schurman Drive	North Pearl Lake Road	County Road 95
Soils	Complex	Complex	Complex	Loam	Clay	Loam	Silty Loam and Silty Clay Loam
Agricultural Parcels/ Buildings	No Parcels	No Parcels	Medium Density of Parcels	High Density	High Density	High Density	Medium Density
Aggregate sources	Road Within 10 miles of an aggregate source	Roads Within 10 miles of an aggregate source	Roads within 10 miles of an aggregate source	Roads within 10 miles of an aggregate source	Roads within 10 miles of an aggregate source	Roads within 10 miles of an aggregate source	Roads within 10 miles of an aggregate source
AADT	N/A	N/A	275	N/A	N/A	N/A	281

Site Investigation: Decision Process							
	1	2	3	4	5	6	7
Case Study roads	Golf Course Road	West Common Road	CO 147	Deroxe Road	Schurman Drive	North Pearl Lake Road	County Road 95
Section 1							
1)	Yes	Yes	No	Yes	No	Yes	No
2)	N/A	N/A	Yes	N/A	No	N/A	No
3)	N/A	N/A	Yes	N/A	No	N/A	No
Section 2							
4)	Yes	Yes	No	No	Yes	Yes	Yes
5)	N/A	N/A	Yes	Yes	N/A	N/A	N/A
Section 3							
6)	No	No	Yes	Yes	No	No	Yes
7)	N/A	N/A	Yes	Yes	N/A	N/A	Yes

APPENDIX L

USING HENNINGS MODEL TO DETERMINE IF CASE STUDY ROADS ARE CANDIDATE ROADS

			Roads with LSTs in Becker and Clay county						
			1	2	3	4	5	6	7
Physical Factors			Golf Course Rd	West Common Road	CO 147	Deroxe Road	Schurman Drive	North Pearl Lake Road	County Road 95
Topography	Grade	Score							
Flat or undulating	<4%	0							
Undulating to hilly area	4-8%	2							
Hilly to mountainous	8-14%	4							
Mountainous with steep sections	>14%	5							
FACTOR SCORE			0	2	4	4	0	0	0
Combination of Climate and Soil Conditions									
Soils mostly suitable for prevailing weather		0							
Soils suitable for prevailing weather only if treated		3							
Soils predominantly are unsuitable as road surfacing for given climate		5							
FACTOR SCORE			0	0	0	0	5	0	5
Socioeconomic Factors									
NONMOTORIZED TRAFFIC DEMAND FOR SURFACING									
Animal or nonmotorized traffic with low volume/demand for sealed surface		1							
Nonmotorized traffic with medium volume/demand for sealed surface		3							
Nonmotorized traffic with high volume/demand for sealed surface		5							
FACTOR SCORE			1	1	1	1	1	1	1
MOTORIZED TRAFFIC VOLUME		1							
<50		3							
50-200		5							
>200									
FACTOR SCORE			1	1	3	3	1	1	3
POTENTIAL IMPACTS OF DUST FORMING									
Slight-minor agricultural area with scarce population		1							
Medium-agricultural area, low -medium density population		3							
Severe-major agricultural area, densely populated		5							
FACTOR SCORE			3	3	3	3	3	1	5
COMMUNITY IMPACT									
Slight-after sealing the road, trade oppurtunities will not change significantly or project will not create any local employments oppurtunities		1							
Medium-Some improvement is anticipated, some employment oppurtunities are created		3							
Severe-Significant improvement is anticipated or extensive employment oppurtunities are created		5							
FACTOR SCORE			1	1	1	1	1	1	3
AVAILABILITY OF QUALITY MATERIAL									
Available and short hauling distance		0							
Available but hauling is more than 10 km		3							
Suitable material is scarce and depleted		5							
FACTOR SCORE			3	3	3	3	3	3	3
GRAND SCORE			9	11	15	15	14	7	20

Appendix L continued

	Golf Course Rd	West Common Road	CO 147	Deroxe Road	Schurman Drive	North Pearl Lake Road	County Road 95
Was an LST successfully built on this road?	Success	Success	Success	Success	Failure	Success	Failure
Henning's-Prediction on whether road is a candidate(recommended minimum scores are within the following range 12-15)	Not a candidate	Not a candidate	Candidate	Candidate	Candidate	Not a candidate	Not a candidate
Dayamba-Prediction on whether road is a candidate	Conduct Site visit	Conduct Site visit	Conduct Site visit	Conduct Site visit	Not a Candidate	Conduct Site visit	Conduct Site visit

APPENDIX M

VEHICLE TYPES AS SPEFICIFIED BY THE MN/DOT

Passenger Vehicles

Type 1

Type 2

Type 3

Buses/ Truck with Trailer – Type 4

2 Axle Single Unit Truck – Type 5

3 Axle Single Unit Truck – Type 6

4+ Axle Single Unit Truck -Type 7

3 & 4 Axle Semi Truck – Type 8

5 Axle Semi Truck – Type 9

6+ Axle Semi Truck – Type 10

Twin Trailer Semi – Type 11,12,13

5 Axle Semi -Split Tandem -Type 16