2014

Investigation of an alternative gravel roads rejuvenation method

Ziliang Zhang
Iowa State University

Investigation of an alternative gravel roads rejuvenation method

by

Ziliang Zhang

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SICIENCE

Major: Civil Engineering (Construction Engineering and Management)

Program of Study Committee:
Charles T. Jahren, Major Professor
Douglas D. Gransberg
Mervyn G. Marasinghe
Elizabeth Hoffman

Iowa State University

Ames, Iowa

2014

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENT

I would like to herein express my heartfelt thanks to my committee chare, Dr. Charles Jahren, and my committee members, Dr. Douglas Jahren, Dr. Mervy Marasinghe and Dr. Elizabeth Hoffman, for their time, encouragement and support along the courses of this research project. My special thanks for time and support from Mr. George Huntington who counseled me at an important time of this research project.

In addition, this research project could not otherwise be able to completed had there not been support and participation of Highway Department of Jackson County, Olmsted County and Beltrami County.

Finally, truful thanks to my families and friends for their considerate care during my life changing 6 months

ABSTRACT

Aggregate surfaced roads become coarser and coarser after a few years of service due to an inherent problem—dust emission. Fine aggregate in the surfacing material is kicked up by passing traffic and blown away as dust. One of the alternative rejuvenation methods is to replenish the missing fines to restore the gradation and plasticity of the in-situ material. Savings in the material and cost could, in return, benefit the environment and financial condition of the jurisdiction. Control and experimental test sections were established in three counties in Minnesota. Performance of test sections were assessed, which included monitoring of cross section profile change, gravel loss and loose aggregate measurements, gravel road condition rating, International Roughness Index, field observation, etc. Experimental sections in Jackson County did not perform satisfactory. However, one of the test sections in Beltrami Counties performed favorably well. A five-year cycle benefit-cost analysis revealed that a 20 percent of cost savings is also achievable in that particular sections. Another trial performed in Olmsted County is also included in this paper. The trial tested if the modified Class 5 Limestone Aggregate is appropriate for gravel road surfacing.

CHAPTER 1: INTRODUCTION

BACKGROUND

In the early United States (U.S.) settlements, trailblazers and pioneers primarily used footpaths aes transportation routes that connected homesteads. Many of these footpaths, which carried horse and wagon loads at the time, survived and became dirt and gravel roads today (Alan L. Gesford and John A. Anderson 2006). There are two general types of road surface nowadays—paved and unpaved road surface. The definition of these two types of pavement varies. According to the definition of US Department of Transportation (US DOT), paved roades eare either a mixed bituminous or bituminous penetration roadway on a flexible or rigid base of various thicknesses or Portland cement concrete roadway with or without bituminous. Unpaved roads are either unimproved roads using natural surface and maintained to permit passability or stone roadways that is drained and graded with soil, gravel and crushed stone, etc. The statistics from Federal Highway Administration (FWHA), as of 2012, there were 1,370,000 miles of unpaved road in the U.S. This number makes up 35% of the total road mileage of 3,981,000(USDOT 2010). Figure 1 shows historic mileage data of both paved and unpaved roads.

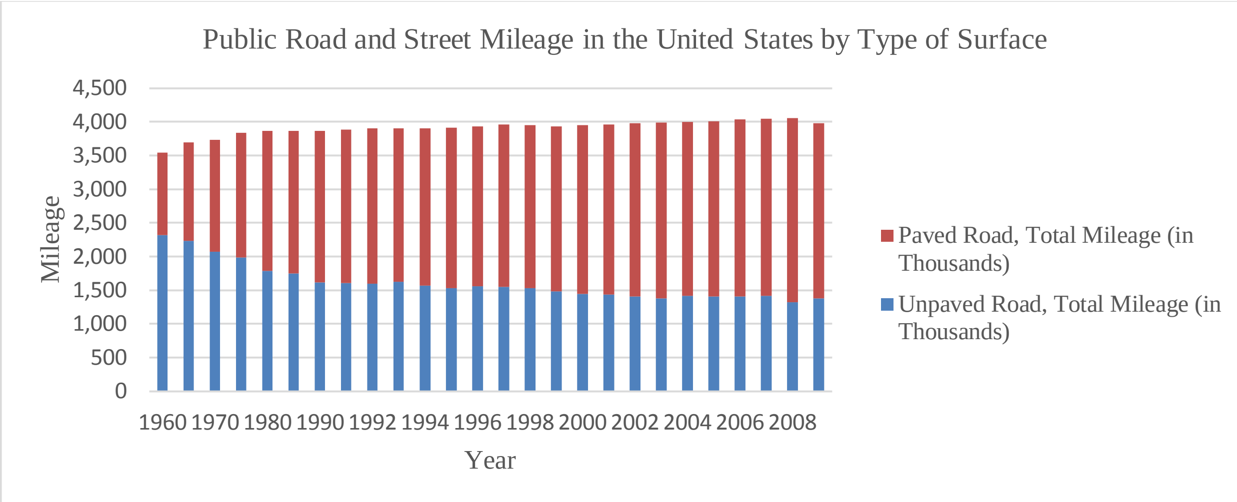


Figure 1 Historic Mileage of Paved and Unpaved Roads in US (USDOT 2010)

Percentage of unpaved roads dropped from 65% in 1960 to about 32% in 1980. Since then, the percentage has remained stable. This is almost one-third of public road mileage supports passage to recreational sites, commuter trips of workers of have residences in rural areas, the transportation of agricultural and industrial products, and with the recent introduction of hydraulic fracturing, oil production materials and products.

Today, gravel roads carry much higher loads than designed loads. Farm sizes in Iowa, for example, have increased nearly 70 percent since 1970 (Project Development Division 1997). In Minnesota (Matthew Oman et al. 2001), the number of farms has decreased by 33 percent, the farm size has increased by 40 percent. Higher concentration of production and modern agricultural practices led to the employment of agricultural equipment and hauling wagons with larger capacities to satisfy the demand. Such situations are also seen in oil industry. Figure 2 shows the annual production of oil in barrels in North Dakota in the last two decades. The production increased in the second half of the period, nearly five-folded. The load capacity of hauling vehicles as well as frequency of passage has increased accordingly. The loading capacity of hauling vehicles as well as frequency of transportation increases accordingly. To meet the needs, it was estimated $567 million of investment over the next 20 year will be required (from 2011 through 2030) to cope with the oil related traffic on the approximate 12,718 miles of impacted unpaved roads (Subhro Mitra et al. 2012).

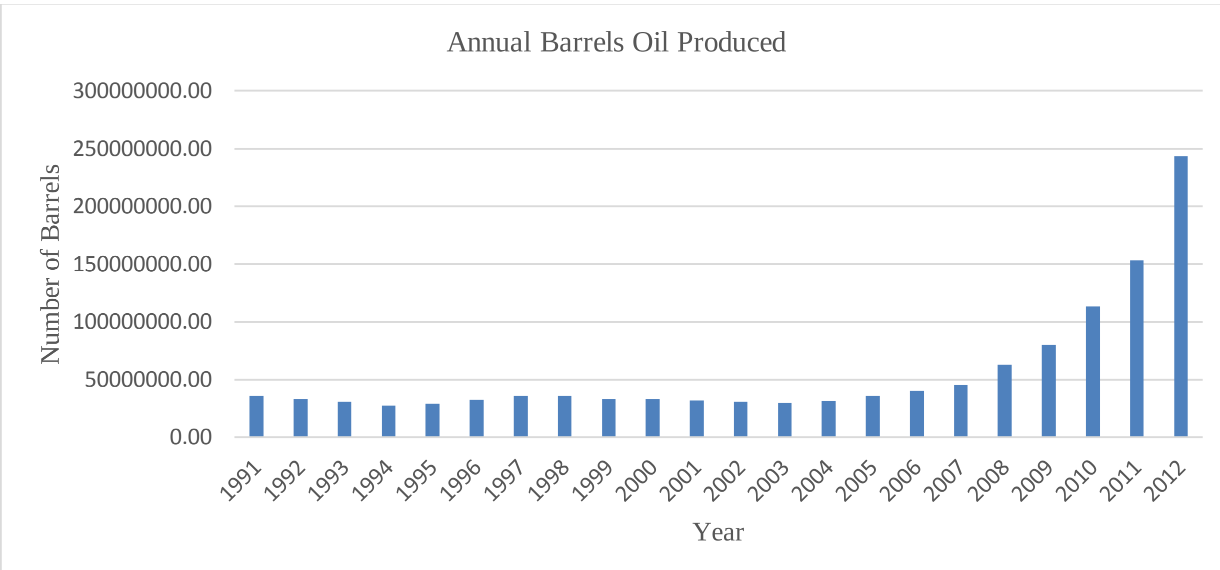


Figure 2 Annual Oil Production in North Dakota (Subhro Mitra et al. 2012)

In fact, unpaved roads such as aggregate surfaced roads are becoming more attractive as an alternative for low volume roads due to the budgetary constraint of local government. States across the nation started to consider going back to the "Stone Age"—that is suspending maintenance on a certain portion of the asphalt roads in certain jurisdictions and simply letting them deteriorate to gravel roads (Charles Taylor 2010).

There is a considerable demand for constructing high quality gravel roads to provide access for users. However, high quality aggregate is depleting and becoming more and more expensive. As FHWA reported that the demand for construction aggregate would continue growing and by the year 2020, the production of aggregate is expected to be 2.5 billion tons per year (Federal Highway

Administration 2004). A wiser use of virgin aggregate is crucial to keep gravel road as a financially and environmentally sustainable low volume road alternative.

PROBLEM STATEMENT

Gravel roads across the state of Minnesota have an Average Daily Traffic (ADT) ranges from 25 to 700 (Eddie N. Johnson and Roger C. Olson 2001). Traffic on gravel roads induce fugitive dust as a result of the disturbance of the surface caused by the wheels of the travelling vehicles. In addition, surface material erosion due to heavy rainfall results in loss of fines in surface material as well. Considering other activities that disturb the road surface such as regular maintenance operations year-round, the fines content in the surface diminishes over the service time. As a result, excessive top size aggregate are left on the road surface as Figure 3 shows.

Figure 3 Loose Aggregate on CR 35, Pope County, July, 2013 (Photo by the Author)

Numerous problems stem from having excessive loose aggregate on the road surface. The loose aggregate tends to accumulate outside of the wheel path, forming ridges. The ridges pair provides "water channel" that retains water. Water retention is believed to be one of the major causes for distresses and failure of a gravel road. Crust formed in the surface will be softened, leading to rutting and potholes (Ken Skorseth and Ali Selim 2000). In addition, excessive loose aggregate compromises the comfort and quality of riding, even impairs the safety of road users under some severe circumstances.

RESEARCH OBJECTIVES

Over the service life, the loose aggregate accumulates to an extent that “re-graveling” is necessary to recover the serviceability of the road. Re-graveling, or re-rocking, a term that some maintenance crew in county highway departments use, involves well graded aggregate transportation and spreading upon affected gravel roads. Re-graveling is one of the prevalent practices among counties to treat such a problem. Such activity would be carried out at certain time interval, depending on a number of factors: availability of the material, Average Daily Traffic (ADT) of the road, types of the material accessible, road condition and others. The maintenance interval varies, although it is common to be within the range of 3-5 years. However, as the resource of quality aggregate is depleting severely, re-graveling is becoming less environmentally sustainable and financially feasible.

County engineers are seeking ways to reutilize the existing aggregate on the surface. The idea of replenishing fines on a road with loose aggregate on the top could be an alternative remedy e(Donald Walker et al. 2001). By mixing in fines, the desired gradation and plasticity of surfacing aggregate could be reestablished. This is critical since proper gradation and plasticity is important in the performance of unpaved roads. (C. T. Jahren 2001). Although, seemly a sensible solution, the result of an investigation that could test this method has not been published. There are incentives to perform an investigation of this type. As the loose aggregate is going to be reutilized, less material is needed to be transported to the site to rejuvenate the gravel road. Therefore, the cost of trucking, a major cost for construction and maintenance activities, and the cost of material is reduced. Since the amount of aggregate needed is lessened, cost of the material drops. Economic benefits are the outcome if the performance is acceptably preserved. Thus, one of the objectives of this research is to monitor and document the performance difference, if any, between the current practices and the proposed practice at gravel road rejuvenation.

Main objectives of this research are outlined as below:

- Assess the performance of proposed road surface rejuvenation method
- Determine the cost effectiveness of adopting the proposed rejuvenation method
- Develop recommendations based on lessons learned through test implementation and observation of the test result.

CHAPTER 2: LITERATURE REVIEW

SURFACING MATERIAL PROPERTY

Gradation

Specifications of surfacing material are readily available in many states and regions. Difference can be found if a horizontal comparison is made among jurisdictions. While some states, such as Minnesota and Iowa, specified surfacing gravel top-sized with ¾” or smaller, other states, such as South Dakota, specified strictly that the top size is smaller than ¾”. That is also true for other sieves within the gradation. For the #200 sieve, Minnesota specifies a range of 3%-10% while Iowa specifies a range of 6%-16% (Iowa Department of Transportation Highway Division 2012; Minnesota Department of Transportation 2005). The difference is even larger for specifications abroad. The #200 sieve is specified to range from 10%-40% in Australia and 7%-30% in South Africa for size of #200 (CSRA South Africa 1989; G. Giummarra, Australian Road Research 2009). These two states are reputed for having good performing gravel roads.

Plasticity

Regarding to plasticity, again jurisdictions provide contrasting specifications according to specification review performed in this report. While many states do recommend the presence of natural silt and clay in the graded aggregate to act as binder which helps to consolidate the aggregate after it is put in place, some states recommend the otherwise. Driving Surface Aggregate (DSA) guideline developed by the Center for Dirt and Gravel Road Studies in Pennsylvania is one of the few exceptions. The guideline stresses that DSA needs be derived from natural stone formations and that aggregate sources are restricted to that which have been mined or quarried from existing geologic bedrock formations. Rock material must make up as much as 98 percent of fines passing the #200 sieve and no clay or silt soil may be added. Lime kiln and cement kiln dust may be added to the DSA to account for up to 50 percent of fines passing the #200 sieve. Surface aggregate must be delivered at "optimum moisture" and be kept damp until placement is completed (Center for Dirt & Gravel Roads Studies 2009).

SURFACING GRAVEL BLENDING EQUIPMENT AND METHODS

Gradation of the existing loose aggregate is likely to be coarser than originally specified since the fines diminish over the service period. To use the existing loose aggregate, adding material with a complementary gradation is advisable. It is desirable to uniformly blend the existing coarser loose aggregate with new finer material that will come close to reestablishing the originally desired gradation. Various methods can be adopted to serve such purposes and used in actual practice.

Motor-grader

A motor grader with a moldboard blade is the most common equipment used for routine maintenance of an unpaved road. The moldboard is set at the predetermined angle β to avoid material spilling and at the proper pitch, at angle of α , to enhance the mixing effect, as shown in Figure 4.

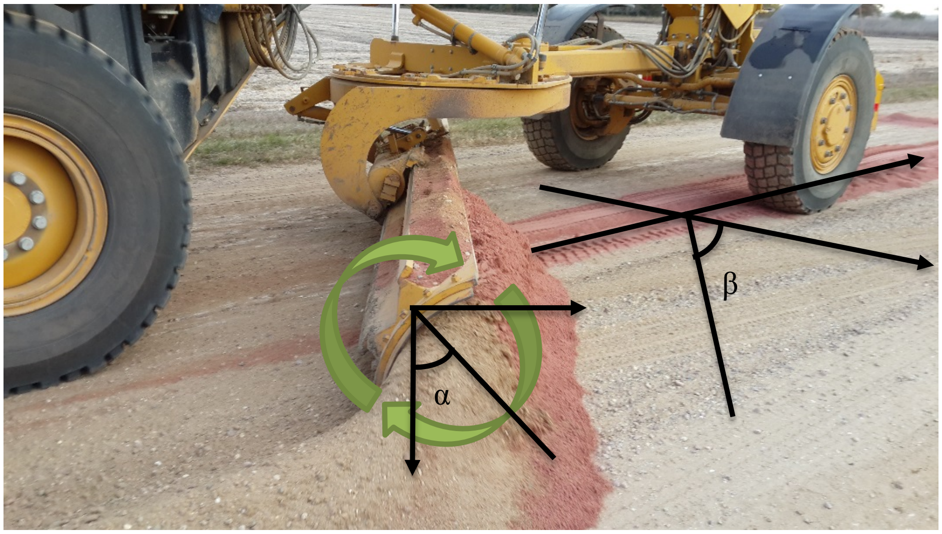


Figure 4 Moldboard Angle and Pitch Illustration (Photo by the Author)

Transported material will be spread upon the stretch of the road to be maintained. Moldboard is lowered to cut few inches into the road surface. Motor-grade then advances at a constant speed of 3-5 mph. Windrows will be established as motor-grader operator attempts to move the material from one side of the road to the other. Several passes back and forth are necessary to evenly distribute material across roads with two lanes.

Carbide-tipped Blade Motor-grader

Instead of using moldboard, in some counties, carbide-tipped grader blade is employed. A photo of carbide-tipped blade is exhibited below in Figure 5. Carbide-tipped blade system brings in a number of benefits (Center for Dirt & Gravel Roads Studies 2005).

1. Durability; carbide-tipped blade has service life as much as three times that of the traditional moldboard.
2. Cutting effectiveness; carbide-tipped blade is more effective for cutting hard surfaces and therefore, allows deeper cut.

3. Improved productivity; since carbide-tipped blade shatters and chisels through rocks rather than pull them out, higher advancing speed is permissible and desired cross section can be achieved. Also, aggregate segregation associated with time-consuming raking is eliminated and thus, costly dust emission is reduced.

Figure 5 Carbide-Tipped Blade (Photo by the Author)

Full Depth Reclamation

Full depth reclaimer is broadly used in asphalt rehabilitation projects. Using full depth reclaimer in aggregate road rehabilitation project is rare, though it is not unprecedented. Virginia DOT (VDOT) conducted a study on the feasibility of deeply mixing particular soil stabilization materials into unpaved roadbeds, intending to lengthen the time interval between maintenance (William Bushman et al. 2005). Equipment that was employed to blend the additive stabilizer is a full depth reclaimer, see Figure 6.

Figure 6 Full Depth Reclaimer (William Bushman et al. 2005)

Asphalt Zipper

Another variation of full depth reclaimer is named Asphalt Zipper™ which is an attachment that can be mounted on another machine such as a track loader as shown in Figure 7. The objective of this equipment is to make asphalt reclamation affordable since owning a self-contained asphalt reclaimer is cost prohibitive for many. Not only does it save money, productivity is drastically increased and performance is improved.

Figure 7 Asphalt Zipper™ (Asphalt Zipper Inc. 2013)

Stockpile Blending

Blending activities do not necessarily have to take place on the road. Sometimes, the material can be mixed and blended off site. To do this, stockpiles of material are placed in close proximity to each other and wheel loaders build a new pile by alternately taking buckets from the original piles. This process is advisable when materials are transported from external resources. Such a mixing process is reported to meet the specification requirements (Ted Eggebraaten and Ken Skoreth 2012).

Figure 8 Stockpile Blending (Ted Eggebraaten and Ken Skoreth 2012)

In another study similar blending procedure was adopted (Thomas J. Wood et al. 2014). The blended stockpile is a mix of Class 5 gravel (MN specification) and Tear off Salvage Shingles (TOSS) in a proportion of 10:4. The stockpile of end product is shown in Figure 9.

Figure 9 Shingles and Gravel Stockpile (Thomas J. Wood et al. 2014)

AGGREGATE ROAD CONDITION ASSESSMENT TECHNOLOGY

Visual Assessment Approaches

The common advantages shared by all visual assessment approaches are that they are time efficient and cost effective. Generally, approaches with visual assessment require fewer training hours, less specialized skills for the rater and less complicated tools, if any are needed. The assessment process involves primarily assigning scores according to described criteria for the severity of each distress based on his/her observation of the assessed section. Various scales may be used. Several mainstream visual assessment systems are briefly described below:

Unimproved Earth PASER System evaluates distresses including Surface Material Makeup, Crown, Drainage, Profile and Ride, Access, Ruts, Potholes, Rocks and Roots and Washboarding (Donald Walker et al. 2001).

Gravel PASER System; the modified rating systems used in Michigan and Wyoming are two variations of the PASER system that that have been widely adopted. They are similar in the way that the assessment is conducted, although rating scale and descriptive criteria are slightly different. The two PASER systems do not evaluate some of the distresses that the Unimproved Earth PASER evaluates such as surface material makeup, riding quality, rocks and roots, and access. Instead, the PASER system evaluates gravel layer and loose aggregate, aside from those distresses commonly shared (Michigan Transportation Asset Management Council (TAMC) 2009; Donald Walker et al. 2001).

Road Surface Management System was developed by University of New Hampshire & FHWA. The system is widely adopted by more than 100 agencies in the state of New Hampshire. The system evaluates all distresses that the gravel PASER system does except for the thickness of gravel layer. Instead of assigning scores, the rater directly assigns the levels of severity according the criteria that corresponds with the method (Charles H. Goodspeed et al. 1994).

Standard Visual Assessment Manual for Unsealed Roads was developed by CSIR Transportek for the Committee of Land Transportation Officials. Three levels of information are introduced. The basic level involves information for road network management. Eight distresses are evaluated to determine the severity. Distresses include Potholes, Corrugation, Ruts, Loose Material, Stoniness, Erosion, Loss of Gravel and Dust. The intermediate level relates to the extent of the mentioned distresses that is rated by estimating the percentage of the road section that is being affected. Advanced level information can also be added which is tailored for the purpose of project management and road research. This information includes thickness of the gravel layer, quality of the gravel layer, shape of the road profile, and the amount of moisture present in the road (D Jones and P Paige-Green 2000).

Subjective Rating System was developed by Central Federal Lands Highway Division. This system evaluates five distresses using a rating scale 0-10. The five distresses include Dust, Washboarding, Raveling, Rutting, and Potholes. The rating system is designed to provide an assessment of test sections. A rating of 5 for test section indicates that the distress level is identical to that of the control section. Ratings above 5 indicate that the test section is in a better condition than control section while ratings below 5 indicate otherwise(Roger W. Surdahl et al. 2005).

Combination of Visual Assessment and Physical Measurement

Although visual assessment has advantages for many reasons, its shortcomings should not be ignored. The visual assessment approaches simply give too much a leeway to the rater. No matter how carefully the rater claims that he/she is following the instruction and criteria, the result is arguable. There are some other methods available that are intended to reveal the true condition of the road.

Objective Rating System was developed by Federal Lands Highway Technology Program in addition to the subjective rating system described in the previous section. Road sections are divided into segments of 0.5 mile to 1 mile. Four randomly selected test areas that are 25 foot by the width of the road surface will be the source of the data. Physical measurements will be implemented in the test areas with respect to each distress. The measurement results will be compared against the criteria to determine a score for each test area. An average score will be assigned to represent the amount of the corresponding distress in each of the segments. The average score for the five distresses in the segment represents the overall rating (Roger W. Surdahl et al. 2005; J. Heather Woll et al. 2008).

Unsurfaced Road Condition Index (URCI) was developed by Department of Army (DOA). The URCI is more sophisticated an approach in comparison to those mentioned above. The unpaved road network is firstly divided into branches by identifying the purpose of the road. Branches include Installation Road, Parking Lot, Motor Pool, Storage, Tank Trail, Range Road, and Other. A branched road is to further divide in distinct segments based on characteristics such as structure, traffic volume, construction history and road rank. Typical sample units are approximately 100ft in length and one is required for every half of a mile or the road. A combination of visual assessment and physical measurement will be conducted to quantify the condition of the unpaved road. Visual assessment is also called “windshield inspection” meaning the inspection will be conducted on a moving vehicle, at a speed of 25mph. For example, dust emission is evaluated using visual assessment. The physical assessment requires a hand odometer, surveying tape, and ruler to measure length and possibly depth of a distresses. The measurements would then be used to derive a deduct value from unique curve for each distress, see Figure 10. A combined deduct value will be subtracted from 100 possible points to obtain the final value. The final value obtained for one section can be used as a network condition metric to compare against that of other sections as well as input for determining maintenance or rehabilitation options (Department of the Army 1995; Robert A. Eaton et al. 1987; R. A. Eatonl et al. 1987).

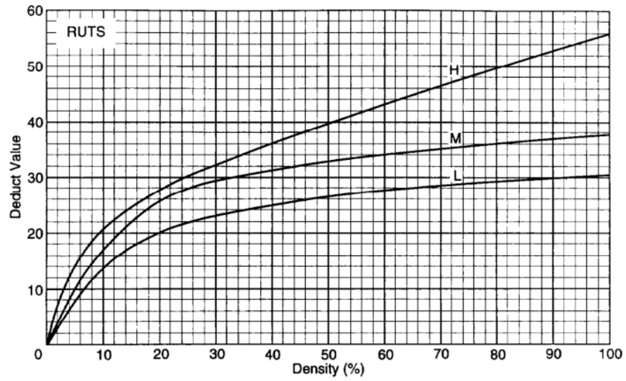


Figure 10 Deduct Value Curve for Distress of Rutting (Department of the Army 1995)

Mass Data Acquisition Approach

The mass data acquisition approach often involves the use of sophisticated equipment. Since mass data can be collected with a modest investment in labor and yet credibility of data collected is enhanced, such approaches are gaining popularity. The required capital investment is much larger for this method in comparison to the foregoing methods mentioned above. As many people realize the tremendous benefit out of the employment of this type of equipment, the expenses of operation and maintenance needed to be considered. Considering that many of the required pieces of equipment are useful for only one task, it is prohibitive to invest in the ownership of all of the equipment that collects all of the necessary data needed to evaluate the overall condition of the unpaved road. Nonetheless, it is interesting to consider some of the equipment commonly used in pavement condition assessment across the globe.

Several systems were grouped to measure roughness.

Longitudinal Profiling System developed by Cybernetics Corporation. The system has modules including an infrared laser, accelerometer, and a distance measuring instrument that is used to collect roughness data for the two wheel paths. Data collected by the two front facing infrared lasers could be processed through algorithm to determine the number and severity of transverse cracks (Federal Highway Administration 2004).

Opti-Grade® was developed by Forest Engineering Research Institute of Canada (FERIC) to collect roughness data on unpaved roads that primarily serve as forest industry logging roads. The equipment is designed to collect roughness data of the road surface on which the Opti-Grade® unit travels on. The Opti-Grade® has three important modules, an acceleration sensor, a GPS unit, and data logging system. Data collected is analyzed by a proprietary software which can feedback information that directs maintenance once a pre-selected roughness redline is passed. So far, the system has been used most frequently on smaller road networks that serve mainly as test tracks for instrumented vehicles. Utilization in a larger road network such as county road system was yet to be explored, by the date of publication (M. Brown et al. 2003).

Roadroid is a smartphone solution to investigate pavement roughness. One of the competitive advantages is that the equipment is portable and yet powerful. Most smartphone have built-in accelerometer sensors, GPS units and data logging systems. Albeit a typical smartphone appears to have all the essential elements that Opti-Grade® has, the level of accuracy afforded mat not be adequate. A smartphone with Roadroid installed can be used as a roughness measurement method providing up to class 3 or 2 accuracy (Michael W. Sayers et al. 1986). The estimated IRI and Calculated IRI are the two methods for calculating for IRI data. The estimated IRI is based on Peak and Root Mean Square vibrations. The device setup procedure for the estimated IRI is the same regardless of types of vehicle used. The estimated IRI is correlated to Swedish laser measurements on paved roads with a correlation factor up to 0.5, which means that it is moderately correlated. Calculated IRI is sensitive to the vehicle types and thus, the type of vehicle is an important input to the setup that is needed in order to receive a correct output. No detailed research has been conducted to study the accuracy at this point yet (Hans Jones and Lars Forslof 2014).

Estimated IRI value thresholds are assigned to four severity levels:

- Estimated IRI less than 2.2; Good
- Estimated IRI between 2.2-3.8; Satisfactory
- Estimated IRI between 3.8-5.4; Unsatisfactory
- Estimated IRI larger than 5.4; Poor

There are four technologies that have been used for automated rut depth measurements (C. R. Bennett and H. Wang 2003).

- Ultrasonic profilometer utilize high frequency sound waves and by interpreting calculations of the traveling time for the echoes that are reflected from the road surface, the profile can be inferred. Ultrasonic profilometers are considered as one of the most cost effective and efficient ways of collecting rut depth data. The typical sampling interval is 2.5-5m.
- Point laser based profilometers utilize high frequency point laser beams to reconfigure the transverse profile using the same principle of ultrasonic profilometer. The laser based profilometer is an upgraded version of ultrasonic profilometers since the sampling volume is larger. The typical sampling interval can be as low as 10mm
- Scanner Laser based profilometers are one category of the remote sensing technology that is employed in road mapping and surveying. A helicopter is one common kind of the vehicle that is used to carry out airborne LiDAR scanning. These sensors are considered as an effective

alternative for data collection on a large scale which turns out to be beneficial from the perspective of asset management at a higher level.

- Optical based profilometers estimate rut depth through digitalized images of the transverse profile. One example is vehicle-mounted INO rut system which uses two lasers and a special camera to measure deformation of the laser line. Road transverse data is collected and processed in real time at traveling speeds of up to 62mph (100km/h) (Romadas 2011). Another great example is unmanned aerial vehicle. Through high resolution images and image processing algorithms, unpaved road distresses can be identifies and measured with high accuracy. It was reported that the measurement has an error less than 1/2 inch (1cm) in measuring rut depth (Chunsun Zhang 2007).

The following paragraphs describe the methods that are available to measure dust emissions on unpaved roads.

Standard Test Method for Collection and Measurement of Dustfall (ASTM D1739 - 98 2010) utilizes sedimentation techniques. This method uses stationary device, open top collectors, usually glass jars or metal or plastic containers. The stationary devices are deployed along the monitor section and exposed to the environment for a certain amount of time, usually 30 days. This sedimentation technique relies on gravitational attraction of particulates and thus, the size of the particulate must be 2 µm or greater. Disadvantages of this method include the lengthy sampling cycle, the need to have agreements with property owners over the installation of the station, vulnerability of the system to be influenced by the addition of dust that is not related to road use.

Road Dust Monitor (RDM) was developed as part of a cooperative study by the Cornell University Local Roads Program and the USDA Forest Service. The RDM can be mounted at the rear wheel of a pick-up truck. The equipment consists of a 20cm (8in.) by 30cm (12in.) duct in which a transducer is installed. The transducer contains a light source and a photoelectric sensor that can emit a light beam as well as detect the reflected light from the subjects such as dust particles (L. H. Irwin et al. 1986). The equipment which is designed based on photometric principle is essentially performing the monitoring by measuring the opacity of air. The advantage of utilizing this photometric technique is that the analysis of the field data occurs in real time which substantially reduces the amount of required laboratory time. However, since the sensor is exposed to the dust as it is detecting the light reflection, it is mandatory to frequently clean the dust from the sensor and therefore the maintenance cost increases accordingly (T. G. Sanders and J. Q. Addo 2000).

Colorado State University Dustometer utilizes a filtration technique. The equipment consists of a filter box, a standard high volumetric (1/3 horsepower) suction pump, a steel bracket attached to a vehicle bumper, 5.08cm (2 in.) flexible hose connecting the suction pump to the filter box, 5000 Watt electric generator, and an on/off switch to control the suction pump. At the bottom of the filter box, there is a filter paper resting on a 200 µm sieve. The equipment is installed at behind the rear wheel on the drive side of the test vehicle which is usually a pickup truck. As the test vehicle travels, the dust kicked up by the rear wheel on the driver's side is sucked up into the filer box. The filter paper is the core part that collects the dust emission. The dust-laden filter paper is moved into a pre-weighed plastic bag and sent to the laboratory for further analysis.

Although the numerous pieces of equipment mentioned above are useful for only one task, some of them are capable of performing multiple tasks. For example, the unmanned aerial vehicle, in addition to previously mentioned distress type is designed as well to measure other distresses such as washboarding, potholes, and others. Decision over the assessment approach is heavily dependent on the available resources that can be allocated for the purpose. Budgetary and time constraints often help determine the most suitable assessment approach whether that approach uses only one piece of equipment or a combination of pieces.

CHAPTER 3: METHODOLOGY

LABORATORY TESTING

In total, 38 samples, both of top layer and bottom layer, were collected and laboratory tests were performed on them.

Sieve Analysis

Aggregate samples were used for gradation tests with a washed analysis according to AASHTO T27 (AASHTO No.T27 2012).

Atterberg Limits

Liquid and plastic limits test were performed on all the collected samples in accordance with ASTM D 4318-10e1 (ASTM International D4318 10e1 2010).

FIELD DATA COLLECTION

Cross-sectional Profile Surveying

Elevation data for a selected number of observation points across selected cross section in the middle of each test section were collected. The objective of this surveying is to reveal the potential loss of aggregate and average elevation changes (Steven Bloser 2007; T. Sanders et al. 1997) at the representative cross-sections for the test sections. A typical cross section profile is shown in Figure 11.

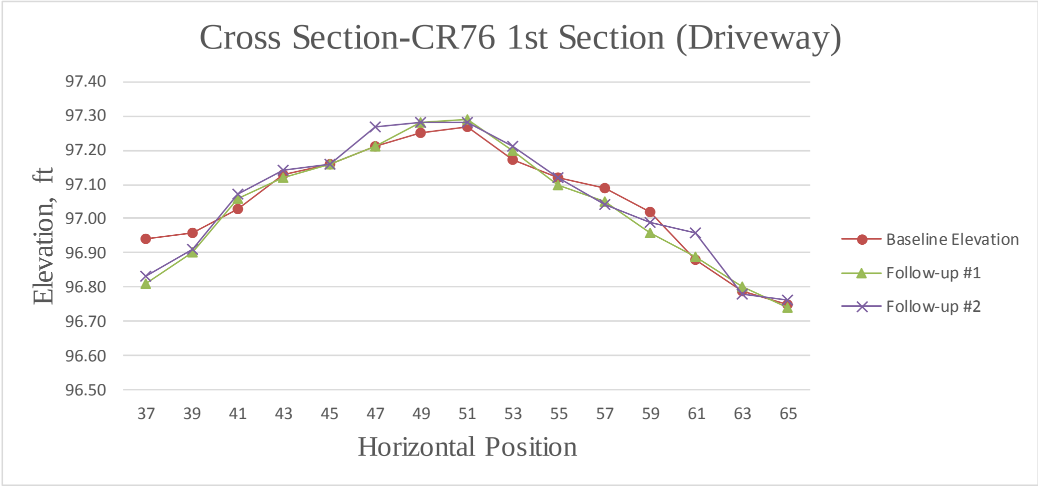


Figure 11 Typical Cross Section Profile

A multiple regression model is presented below to represent the cross-section profile upon which statistically analysis was performed, considering the elevation, y_{ij}, of each surveyed point is only dependent on the time, x_i, (the reading soon after construction and the reading during the observation period) and the location of the point, x_j. The variable x_i is a categorical variable and x_j is a numerical variable.

A model with only stand-alone terms, x_i, x_j and x_j^2, solely explains a situation where the cross section experiences an overall change in elevation. In other words, the elevation of each data point is either higher or lower than that of the first reading. However, this is not always true. For an aggregate road, it is very common to observe uneven deterioration. In addition, due to regular maintenance processes, one side of the road could possibly become higher than it was when it was constructed. The introduction of $x_i x_j$ and $x_i x_j^2$ was to account for such situations.

$$y_{ij} = \beta_0 + \beta_1 x_i + \beta_2 x_j + \beta_3 x_j^2 + \beta_4 x_i x_j + \beta_5 x_i x_j^2 + \varepsilon_{ij}$$

Where $x_i = \begin{cases} 0, & \text{Baseline} \\ 1, & \text{Follow-up} \end{cases}$, $x_j = x_1 + x_2 + ... + x_n$, n varies from section to section

The JMP statistical software application package is used to output value information including a Summary of Fit and a Parameter Estimate. The summary of fit table gives information about how meaningful the model is with regard to the collected data, that is, how much variation is explained by this regression model. The parameter estimates table provides clues regarding whether or not any of the variables contains useless information about y, that is, if the coefficient of the variable is zero or not. The interest here is to find out if the coefficients of the time variable and variables that include time are zero or not. If the coefficients are zero, it means the elevation is not time related which means that no statistically significant change in cross section occurred over the observation period.

Unpaved Road Condition Rating

The rating system used in this research had been previously used in a Geographic Information System-based asset management program in Wyoming (George Huntington and Khaled Ksaibati 2005). The rating standard was sent to the research team by Mr. Huntington. The development of the rating standard was influenced by numerous rating systems including:

- Unsurfaced Road Condition Index (URCI) (Department of the Army 1995)
- Utah LTAP Center's Transportation Asset Management System (TAMS) (Utah LTAP 2011)
- Wisconsin Transportation Information Center's Pavement Surface Evaluation and Rating (PASER) system (Donald Walker et al. 2002)
- CSIR of South Africa's Standard Visual Assessment Method for Unsealed Roads (D Jones and

P Paige-Green 2000)

- The Australian 'Unsealed Roads Manual: Guidelines to Good Practice', 3rd Edition (G. Giummarra, Australian Road Research 2009)
- The Wyoming T/LTAP Center's Gravel Roads Management Report (George Huntington and Khaled Ksaibati 2010)

General distresses such as rutting, wash boarding, and others, are evaluated with this rating standard. Images of categorized distress severity levels were attached in the material provided by Mr. Huntington to serve as a guideline for rating.

This rating standards was selected for its simplicity and the efficiency of use. With time and budgetary constraints, travel frequency was limited for the researchers, so the majority of rating tasks were carried out by county personnel. A standard rating manual was sent to the person who would carry out the task. The manual was intended to guide the rater to properly rate each distress according to one standard so that results would be comparable regardless of the experience of the rater and other elements that might influence the results.

Dynamic Cone Penetrometer (DCP) s

DCP tests were performed on the wheel paths to investigate the shear strength of the supporting road layers. Four cycles of test were performed at most of the test sections at locations randomly selected. The DCP test measures penetration rate that may be related to in-situ material strength by estimating the in-situ CBR (California Bearing Ratio). ASTM D6951/D6951M-09 standard was followed (ASTM Standard D6951/6951M 2009).

Light Weight Deflectometer (LWD)

LWD measurements were performed at random locations on the wheel path in each test section. LWD is generally used for testing the stiffness of the unbound pavement by measuring the deflections. Procedures instructed by ASTM International E2583-07 were followed (ASTM International E2583-07 2011).

Scrape Test

Scrape test was a customized test that the research team developed to estimate the amount of loose aggregate on the surface.

FIELD DATA COLLECTION AND SAMPLING PROCEDURE

Sampling

For a typical aggregate-surfaced road, the surfacing layer segregates during its service life into two layers: a top floating aggregate layer and a bottom compacted aggregate layer. The material in these two layers were collected separately. A customized hoe with a wing plate on each side to mitigate the loss of material, as shown in Figure 12, was made to collect loose aggregate into a shovel. The collected material was transferred into a heavy duty plastic zip bag to preserve it for further analysis.

Figure 12 Loose Aggregate Collection (Photo by the Author)

Figure 13 Customized Hoe (Photo by the Author)

It should be noted that the hoe effectively limited the area from which the loose aggregate was collected. Therefore, it is possible to estimate the volume or weight of loose aggregate on the surface that was collected with the 6-inch wide customized hoe, see Figure 13. Three random locations in the each test section were selected for conducting the scrape test, since it is unrealistic to collect all of the loose aggregate within a test section. Careful attention is to limiting the down pressure during scraping is necessary as the compacted layer was not supposed to be disturbed in order to produce a reliable estimate, Figure 14.

Figure 14 Controlled Area for Top Material Collection

To collect the bottom compacted aggregate, a pick was used to dig down and loosen the compacted aggregate and ease the sampling process. Compacted material was sampled to a depth of 2 inches on average as shown in Figure 15. The collected material was transferred into a heavy duty plastic zip bag to preserve it for further analysis.

Figure 15 Bottom Compacted Aggregate Collection (Photo by the Author)

Cross-Section Elevation Measurement

Establishing a reliable benchmark is critical for the success for capturing an elevation cross-section profile. The research team made use of power poles on the side of the road to determine and mark the location of each cross-section. The research team then drove a screw into each power pole and sprayed red paint around it, as shown in Figure 16. The elevation of the screw was used as the benchmark for surveying.

Figure 16 Red-Painted Benchmark on Power Pole (Photo by the Author)

The researchers used an optical automatic level for surveying as shown in Figure 17.

Figure 17 Automatic Level for Cross-Section Elevation Reading (Photo by the Author)

Steel pins, see Figure 18, were used to indicate the second and the last points of each reading. Steel pins were placed beyond the roadway at a convenient location. Readings were taken every two feet.

Figure 18 End Indicator-Steel Pin (Photo by the Author)

A typical cross section profile is shown in Figure 19.

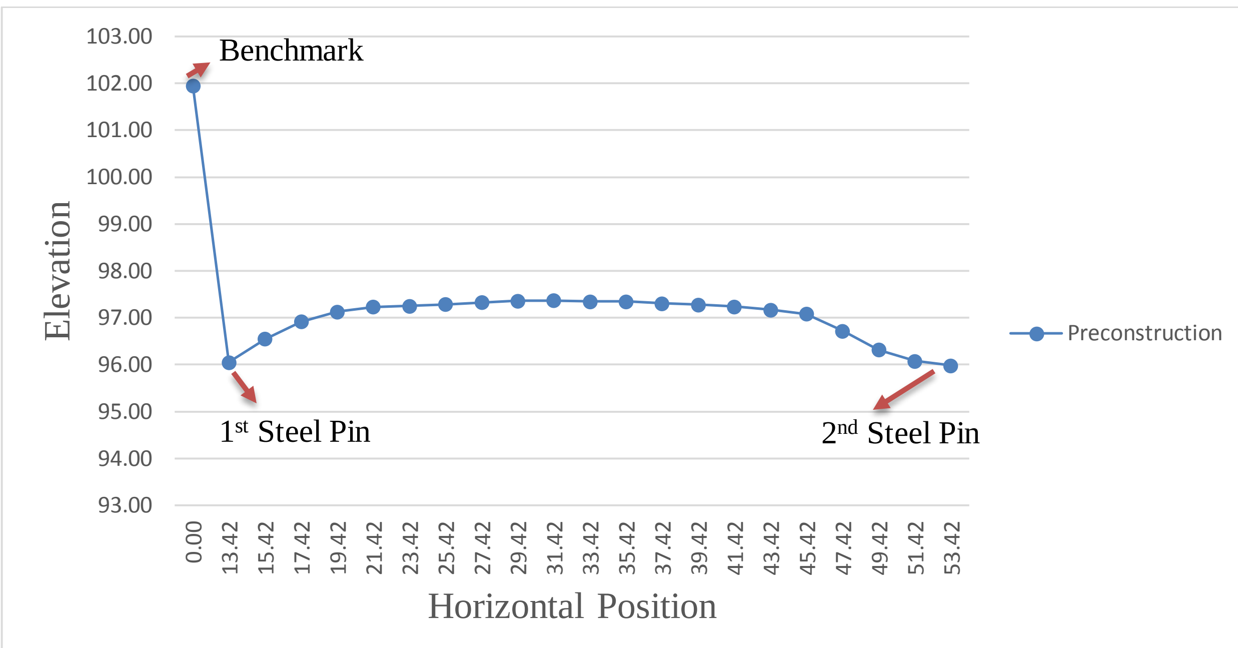


Figure 19 Typical Cross Section Profile

DCP and LWD Test

DCP and LWD tests were conducted primarily to investigate the shear strength and stiffness in the area of the wheel paths. A wheel path is track on road surface that has frequent contact with the wheels of the travelling vehicles.

PRECONSTRUCTION OBSERVATIONS

Pope County

The research team visited Pope County in July, 2013. CR 35 was considered a typical road section that has a considerable amount of loose aggregate, see Figure 20. The volume of loose aggregate was estimated to be 307.24 tons/mi based on an estimate involving the scrape test.

Figure 20 Loose Aggregate on CR 35, Pope County (Photo by the Author)

Jackson County

The research team visited Jackson County CR 76 test site twice, in July and August, 2013, before construction. Figure 21and Figure 22 show the surface conditions at the time of those visits.

Figure 21 Jackson County Road 76 Surface Conditions in July, 2013 (Photo by the Author)

Figure 22 Jackson County Road 76 Surface Conditions in August, 2013 (Photo by the Author)

Scattered loose aggregate was seen along the road but was not considered serious. Loose aggregate accumulated away from the wheel path. Whipped-off coarse aggregate was seen along the shoulder. Loose aggregate volume was estimated to be 186 tons/mile according to the estimates based on scrape test results.

The road did not comply with typical recommendation for crown slope which is 4%-6% (Ken Skorseth and Ali Selim 2000; Center for Dirt & Gravel Roads Studies 2005). Our measurements show the eastbound cross slope was 2.9% and the westbound side was 3.3%. The road, from the perspective of the research team, is moderately dusty during dry season.

Beltrami County

The research team visited the Beltrami County CR 23 test site once in July, 2013, before construction. The loose aggregate problem was not pronounced, as shown in Figure 23, although there was scattered loose aggregate.

Figure 23 Beltrami County Road 23 Surface Conditions in July (Photo by the Author)

Loose aggregate tonnage was estimated to be 91.3 tons/mile according to estimates based on scrape test results. The road did not comply with typical recommendation for crown slope. Measurement showed that the northbound cross slope was 1.2% and the southbound side was 1.9%.

Olmsted County

The research team visited the Olmsted County CR-115 test site once in July before construction. A small amount of loose aggregate was present on the road. Wheel paths were clearly seen in Figure 24. The wheel paths were highly compacted and had the appearance of an aged pavement.

Figure 24 Olmsted County Road 115 Surface Conditions in July (Photo by the Author)

Loose aggregate tonnage was estimated to be 71.49 tons/mile. The road has an effective crown slope. Our measurement shows that the northbound cross slope is 6.7% and the southbound side is 6%.

CONSTRUCTION PROCEDURES

A brief outline of construction procedures for each county test site is provided below.

Jackson County

Construction was completed at Jackson County test site October 25, 2013 (Figure 25 through Figure 30). The construction for each test section included the following activities:

1. Windrowing existing loose material at the centerline of the road
2. Spreading additional material over the windrowed existing material
3. Blending the existing material and the crusher dust by blading two times with the motor grader

Figure 25 Surface Gravel Windrowing (Photo by the Author)

Figure 26 Crusher Dust Tailgating (Photo by the Author)

Figure 27 Material Blending (Photo by the Author)

Figure 28 Jackson County Road 76 East Test Section (Photo by the Author)

Figure 29 Jackson County Road 76 Mid Test Section (Photo by the Author)

Figure 30 Jackson County Road 76 West Test Section (Photo by the Author)

It is noticeable that the two experimental sections looked differently from the control section. Reddish path along the road suggests the concentration of crusher dust. More passes of blading or more crusher dust seem necessary to evenly distribute the crusher dust across the road surface.

Beltrami County

Construction was completed at the Beltrami County test site November 7, 2013 (Figure 31 through Figure 34). The construction process for each test section included the activities:

1. Stripping the top 1 inch of surfacing aggregate and then windrowed on the side
2. Spreading additional material for the test section at the centerline of the road
3. Blending the existing material and crusher dust with two passes for each side of the road

Figure 31 Beltrami County Road 23 South Test Section (Photo by the Author)

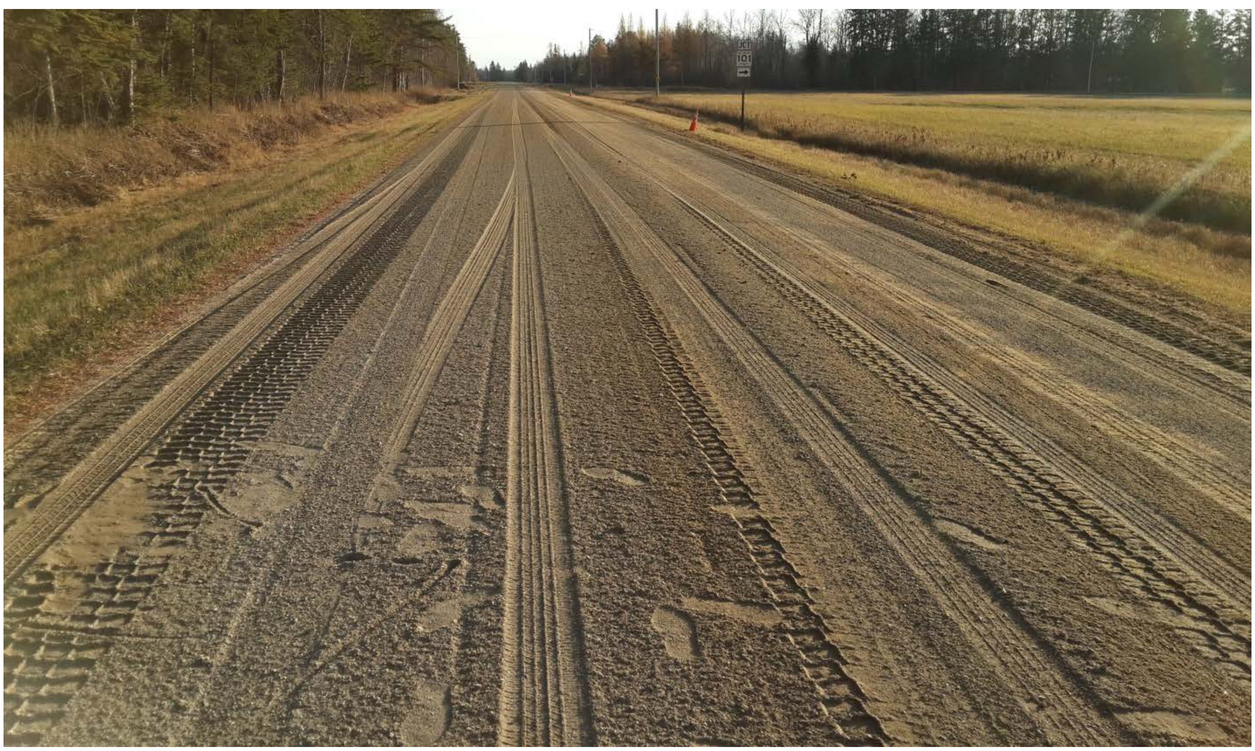


Figure 32 Beltrami County Road 23 Mid Test Section (Photo by the Author)

Figure 33 Beltrami County Road 23 North Test Section (Photo by the Author)

Figure 34 Standard Class 1 (left) and Crusher Dust (right) (Photo by the Author)

The two experimental roads looked quite different as one of the crew pointed out for its lighter surface color. Crusher dust was evenly distributed across the width of the road on the two sections.

Olmsted County

The research team was not able to observe construction, therefore construction notes for the Olmsted County test site were solicited from the maintenance supervisor. The mixing process for

Section 2 was accomplished in the quarry. A truck was loaded with two buckets of Class 5 and one bucket of lime with the process repeated until the truck was fully loaded. The mixing process for Section 3 was implemented on site. Class 5 was spread and leveled before Class 2 was spread on top of the Class 5 material. According to county personnel the following construction procedure was used:

1. Material was spread and a motor grader blade flattened the material on the road
2. A water truck sprayed water to pre-wet the material
3. The material was windrowed and spread across the road in about three rounds
4. Water was applied to the road and the material was roller compacted

TEST SECTION DESCRIPTION

Three counties participated the research project. They are Jackson, Beltrami, and Olmsted County. Detailed description of test section plans for each county follows. All sites were chosen based on the following criteria:

- Appropriate longitudinal geometry profile
- Moderate average daily traffic
- Moderate loose aggregate problem appearance

Jackson County Test Section Layout

The location of CR 76 is shown in Figure 35. Three test sections were established on CR 76, Jackson County, one of which serves as a control section and the other two are experimental sections. CR 76 has longitudinal slope from -0.7% to 1%. Each test section is 500ft long, see Figure 36. The crusher dust is non-binding crushed stone commonly used in the area as aggregate for microsurfacing. The control section used MnDOT specified Class 5 aggregate. Class 5 aggregate was imported from Anderson Pit which is operated by Duininck Bros, Inc., IA. The amount of material added for each test is shown in the Table 1.

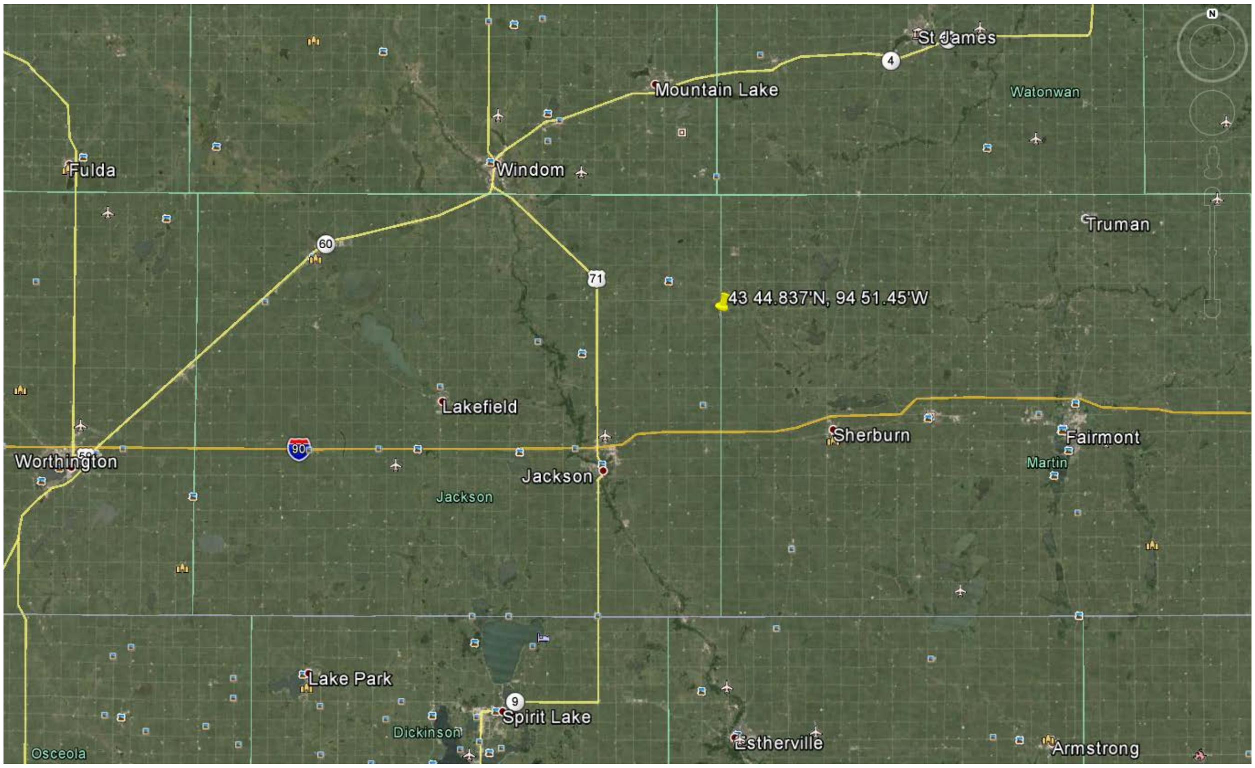


Figure 35 Location of CR 76 in Jackson County

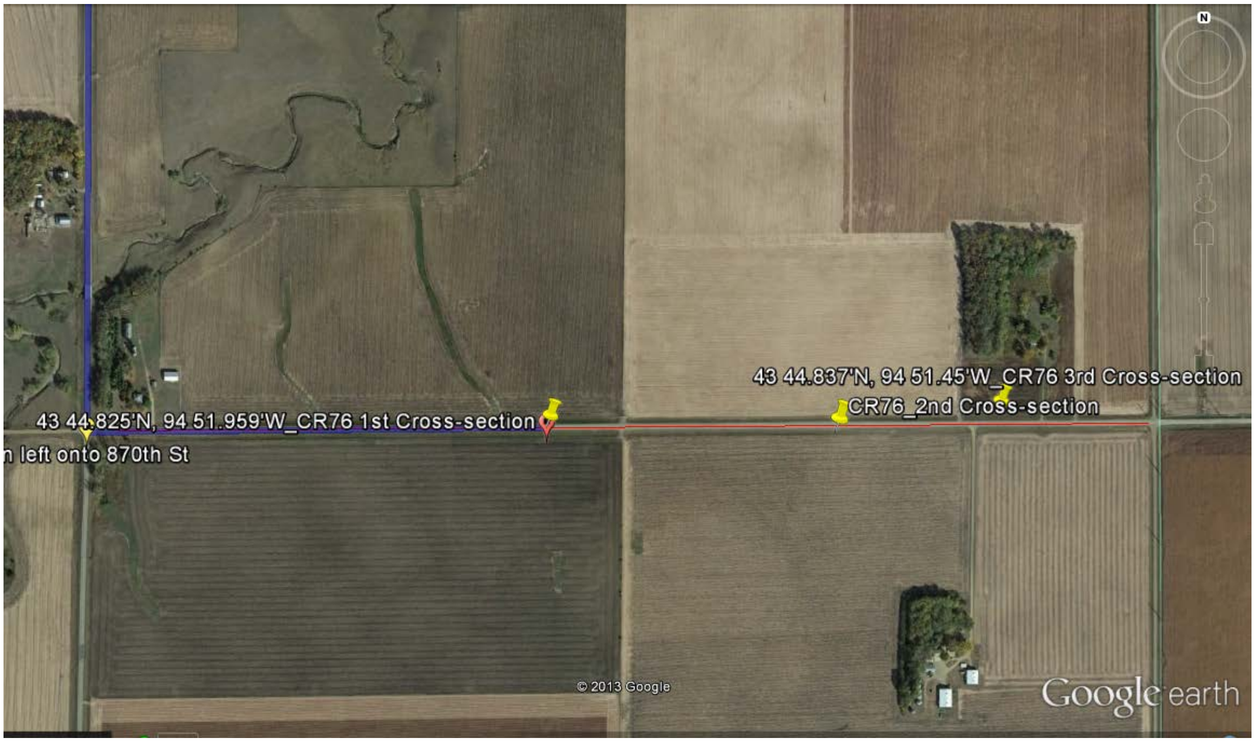


Figure 36 Plan View of Jackson County Road 76 Cross-sections

Table 1 Amount of Aggregate Added-Jackson County

Jackson County		
	Type	**Amount of material (tons)**
West Test Section/1st Section	Class 5 St'd Material	19
Mid Test Section/2nd Section	Crusher Dust	12
East Test Section/3rd Section	Crusher Dust	7

Beltrami County Test Section Layout

The location of CR 23 is shown in Figure 38. Three test sections were established on CR 23, Beltrami County. CR 23 had longitudinal slope ranging from -0.8% to 1.1%. Likewise, two experimental sections and one control section were established, 1/3 mile for each section, see Figure 38. The control section used MnDOT specified Class 1 aggregate which is used in the area for surfacing. The two experimental sections used crusher dust derived from granite. See Table 2 for the amount of aggregate used in each section. The source of dust was from Knife River Material and Class 1 aggregate was originated from Poxleitner Pit.

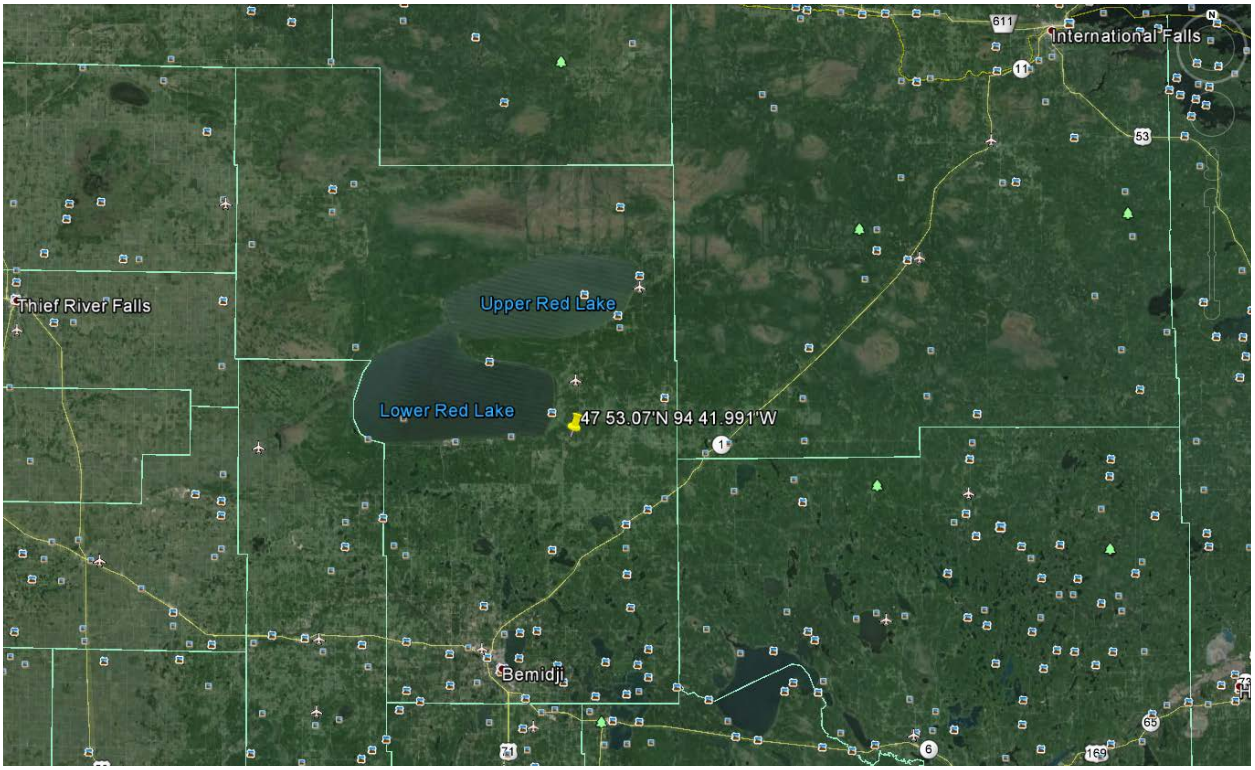


Figure 37 Location of CR 23 in Beltrami County

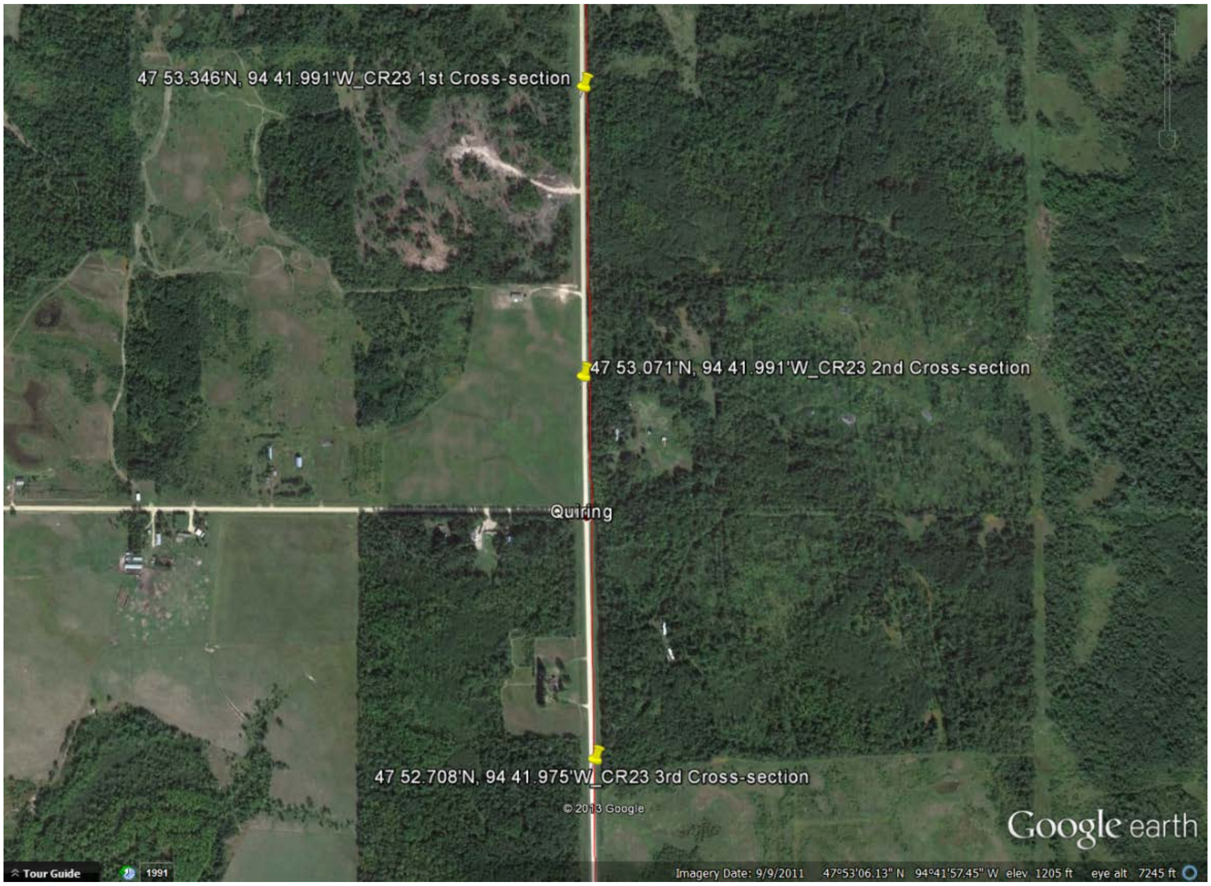


Figure 38 Plan View of Beltrami County Road 23 Cross-sections

Table 2 Amount of Aggregate Added-Beltrami County

Beltrami County		
	Type	**Amount of material (tons)**
North Test Section/1st Section	Class 1 St'd Material	166
Mid Test Section/2nd Section	Crusher Dust	83
South Test Section/3rd Section	Crusher Dust	50

Olmsted County Test Section Layout

The location of CR 115 is shown in Figure 39. There were four test sections established on CR 115. The four test sections could not be laid out adjacent to each other due to the geometry of the road and intermittent application of stabilization additive along the road. Figure 40 shows location of the four test sections. The four sections were established on the segments of the road where it is flat and no dust palliative was applied.

Length of 1st to the 4th test section was 1005ft, 1148ft, 1000ft and 1010ft, respectively. Section 1 used standard Class 5 virgin material was used for Section 1. Standard Class 5 virgin material mixed with one-third lime was used for Section 2. A 1:1 mix of standard Class 5 and standard Class 2 virgin material was used for Section 3. Standard Class 2 virgin material was used for Section 4. Amount of material placed is tabulated below in Table 3.

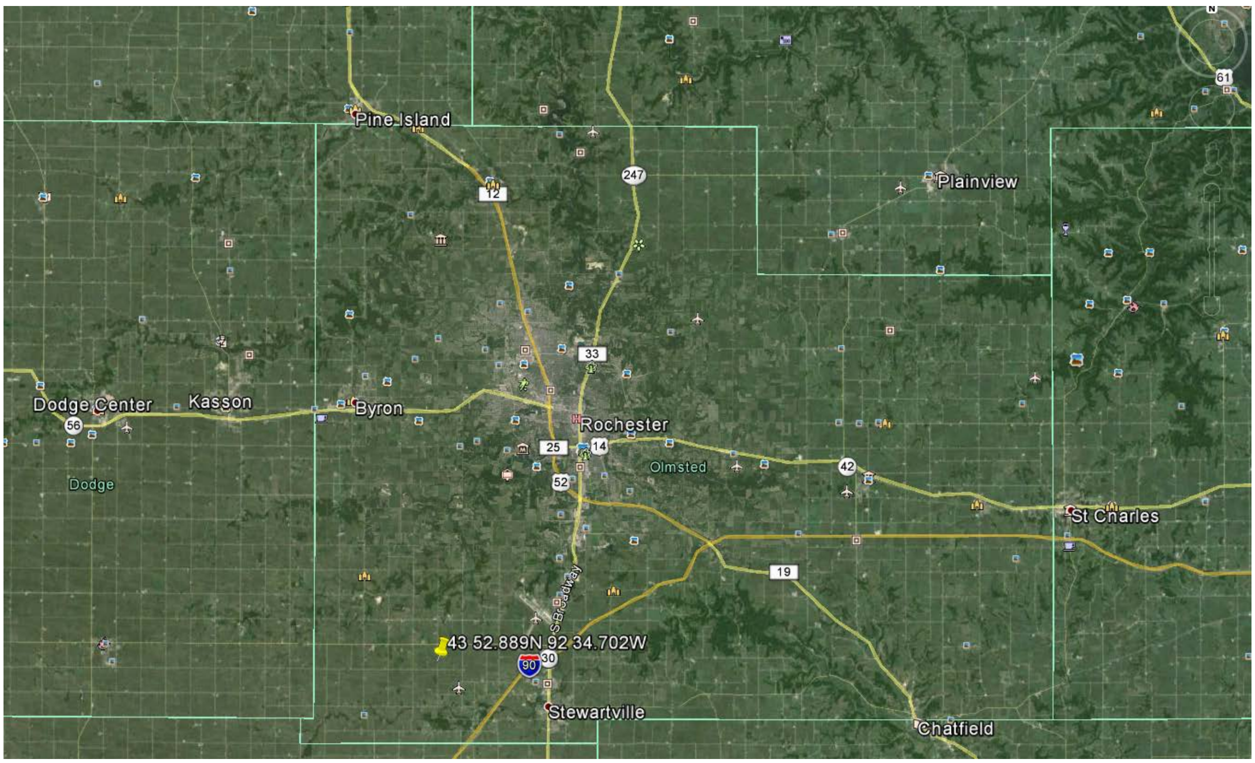


Figure 39 Location of CR 115 in Olmsted County

Figure 40 Plan View of Olmsted County Road 115 Cross-sections

Table 3 Amounts of Material Added on Olmsted County Road 115

Olmsted County		
	Type	**Amount of material (tons)**
Section 1	Class 5	234.94
Section 2	2/3 Class 5 and 1/3 Lime	160.75+90.65=251.4
Section 3	1/2 Class 5 and 1/2 Class 2	121.5+121.5=243
Section 4	Class 2	270

Traffic Volumes

MnDOT average daily traffic (ADT) counts of 2012 are shown for the Jackson County and Beltrami County sites, and that of 2010 for the Olmsted County site are shown in Table 4.

Table 4 Test Section Traffic Volumes Statistic

2012 Traffic Volume	ADT
Jackson	35
Beltrami	80
Olmsted (2010 Traffci Volume)	95

Maintenance Activity Timetable

Maintenance activities were logged and presented in the following tables.

Table 5 Maintenance Activities Timetable-Jackson County

Jackson County CR76	
	Data
Construction	10/25/2013
1st Maintenance	10/30/2013
2nd Maintenance	11/18/2013
3rd Maintenance	4/16/2014
4th Maintenance	5/21/2014

Table 6 Maintenance Activities Timetable-Beltrami County

Beltrami County CR23		
	Data	**Remark**
Construction	11/7/2013	
1st Maintenance	4/27/2014	South section alone
2nd Maintenance	5/15/2014	All three sections
3rd Maintenance	6/9/2014	All three sections
4th Maintenance	6/16/2014	South section alone
5th Maintenance	7/18/2014	All three sections
6th Maintenance	8/6/2014	South Section
7th Maintenance	9/11/2014	All three sections
8th Maintenance	9/29/2014	All three sections
9th Maintenance	10/16/2014	South and middle section

Table 7 Maintenance Activities Timetable-Olmsted County

Olmsted County CR115	
	Data
Construction	9/3/2013-9/4/2013
1st Maintenance	10/4/2013
2nd Maintenance	5/19/2014
3rd Maintenance	7/15/2014

CHAPTER SUMMARY

Test sections were constructed in Jackson County, Beltrami County and Olmsted County.

In Jackson County, three sections were established on County Road 76. For the two experimental sections mixed different amounts of crusher dust, which is commonly used for micro-surfacing was mixed with the in situ loose aggregate. Class 5 aggregate was used for the control section.

In Beltrami County, three test sections were established on County Road 23. Different amounts were mixed in with the in-situ loose aggregate in the two experimental sections. Class 1 aggregate was used for the control section.

In Olmsted County, four sections were established on County Road 115. For the two control sections, Class 2 and Class 5 aggregate were used as the surfing material. The two experimental sections used a 1:1 mix of Class 2 and Class 5 and a 2:1 mix of Class5 aggregate and lime were used, respectively.

CHAPTER 4: RESULTS

SOIL COMPOSITION COMPARISON

Unlike paved roads, the unpaved roads often time end up with loose aggregate scattered over the surface due to the loss of fine binding material because it is blown away when traffic stirs it up or because it is washed off with the rain water. The loose aggregate can no longer bear loads from the traffic. However, on most aggregate roads, the wheel paths are highly compacted which suggests that given a proper gradation, an unpaved surface can reach high levels of compaction even though it is compacted by typical traffic alone. An understanding of the soil composition of the loose aggregate (hence after “top material/aggregate”) and that of the compacted bearing layer (hence after “bottom material/aggregate) is of interest.

The research team conducted an extensive investigation regarding the gradation difference between the top and bottom layers of aggregate. In addition to samples collected in Minnesota, samples were also collected in Boone and Story Counties in the State of Iowa from roads that were considered to be having issues with loose aggregate, though the level of severity varied. In total 19 pairs, representing both bottom and top material were collected from various roads. An independent t-test was performed to detect statistically significant differences in content percentage for each soil classification comparing the top and bottom layers. A bar chart comparison for each soil classification is shown below, in Figure 41.

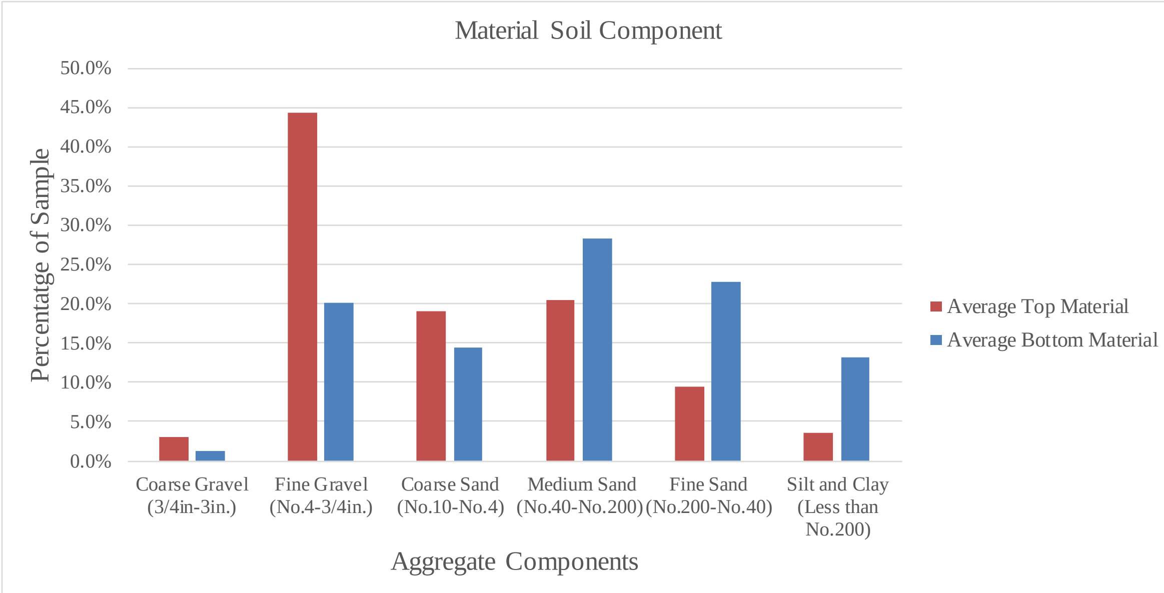


Figure 41 Comparison in Soil Classification

The test result suggests that for all categories, except for coarse gravel, a statistically significant difference was detected. The proportion of silt and clay particles, which serve as binder for unpaved roads, was about 3.6 times higher in the bottom layer in comparison to the top layer. The bottom layer also has higher percentage in medium sand and fine sand. Not surprisingly, for the top layer, fine gravel that has size ranging from No.4 (4.75mm) to ¾ inch (19mm) dominates and makes up nearly 45% of the composition. The absences of fine sand and silt and clay by a considerable amount is a likely explanation for the segregation that is a common occurrence on aggregate roads. The bar chart visually exhibits the composition difference between the top and the bottom layers.

JACKSON COUNTY

Material Properties

The particle size distributions (PSD) of material before and after construction are presented below in Figure 42. Two solid lines represent the PSD curve for top and bottom layers of material, as indicated. PSD curve for three test sections lies in between the two solid lines at their left tails, indicating the gradation of the top layer has been modified and become finer.

Detailed material properties are summarized in Table 8. The proportion of #200 fine particles increased after crusher dust was mixed in. However, the crusher dust has zero plasticity.

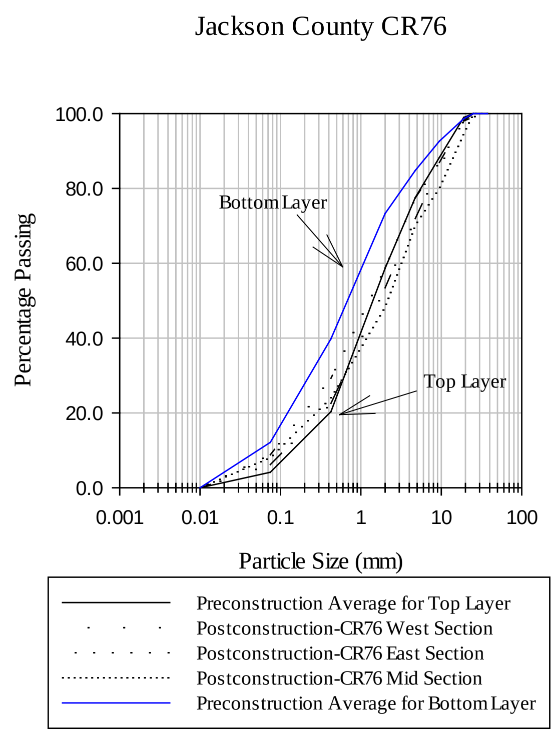


Figure 42 PSD of Material-Jackson County CR 76

Table 8 Detailed Material Properties after Mixed in-Jackson CR 76

Jackson County									
Sieve Size	Percentage Passing			Percentage Passing			Percentage Passing		
	East CR76		Average	Mid CR76		Average	West CR76		Average
	#1	#2		#1	#2		#1	#2	
1.5"	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
1"	98.3%	100.0%	99.1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3/4"	96.1%	100.0%	98.1%	96.0%	93.3%	94.6%	98.2%	98.0%	98.1%
3/8"	84.0%	90.1%	87.1%	83.1%	77.3%	80.2%	86.9%	84.2%	85.6%
#4	73.9%	81.2%	77.5%	73.7%	66.7%	70.2%	74.8%	69.0%	71.9%
#8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
#10	55.6%	62.1%	58.9%	51.3%	45.4%	48.3%	56.5%	50.2%	53.3%
#30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
#40	27.2%	31.4%	29.3%	25.8%	22.3%	24.1%	23.8%	21.2%	22.5%
#100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
#200	7.9%	9.8%	8.9%	8.8%	7.5%	8.2%	6.5%	5.9%	6.2%
<#200	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Liquid Limit	13.3%			15.3%			14.9%		
Plastic Limit	15.0%			15.5%			15.1%		
Plastic Index	0.00			0.00			0.00		

DCP and LWD Test

Figure 43 reveals that the surface and the subgrade materials are rather consistent with regard to stability since penetration rate (PR) does not change, except for the Middle Section. From the plot for the Middle Section, a pronounced downturn is seen at about 120mm (4.7in) from the surface, suggesting heterogeneity of subgrade material. California Bearing Ratio (CBR) appears to be comparable between West and East Section. However, according to some measurements, the CBR increases to 300 within the wearing surface in Middle Section. Plots are shown in Figure 44.

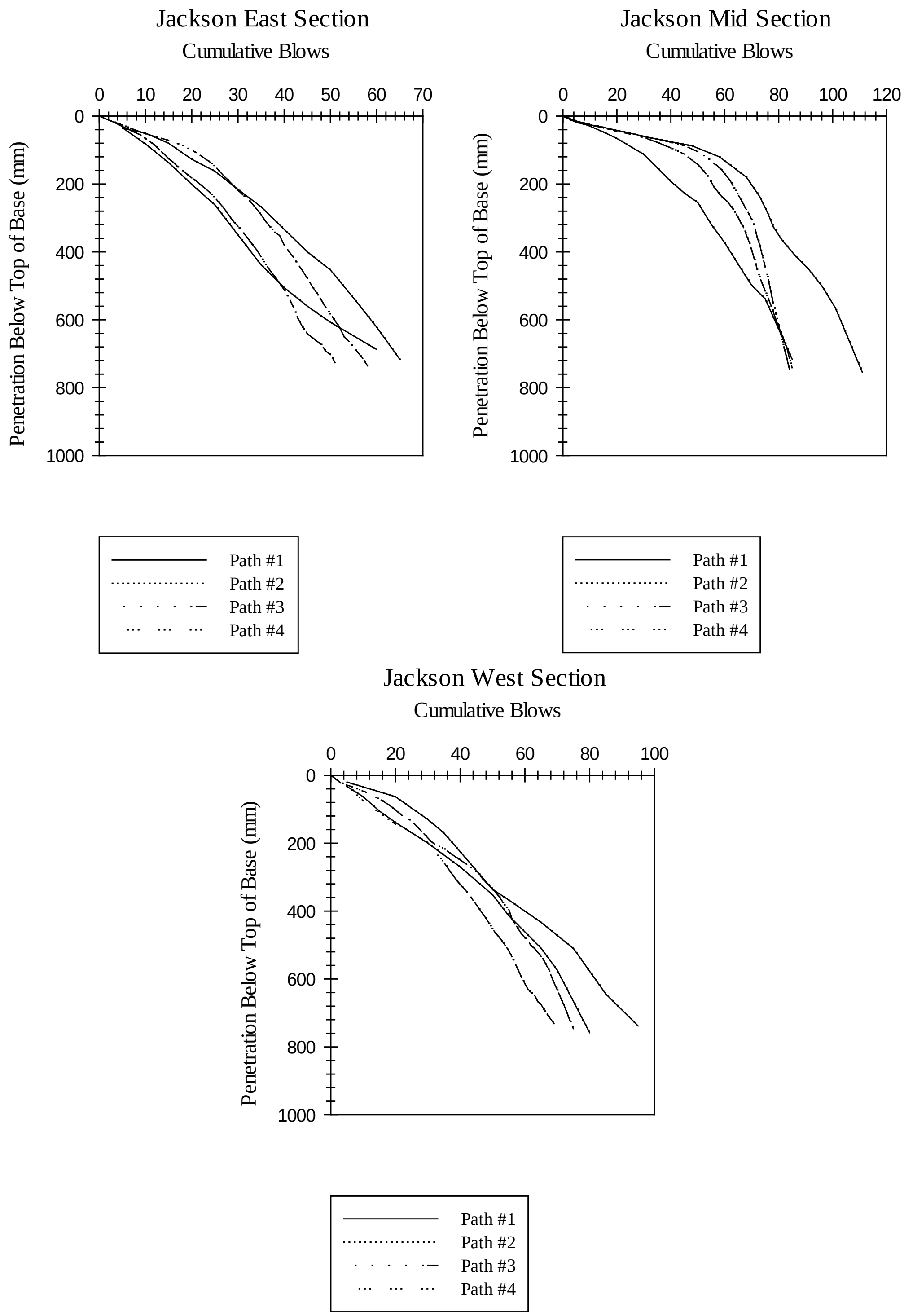


Figure 43 Cumulative Depth against Cumulative Blow-Jackson County (6/21/2014)

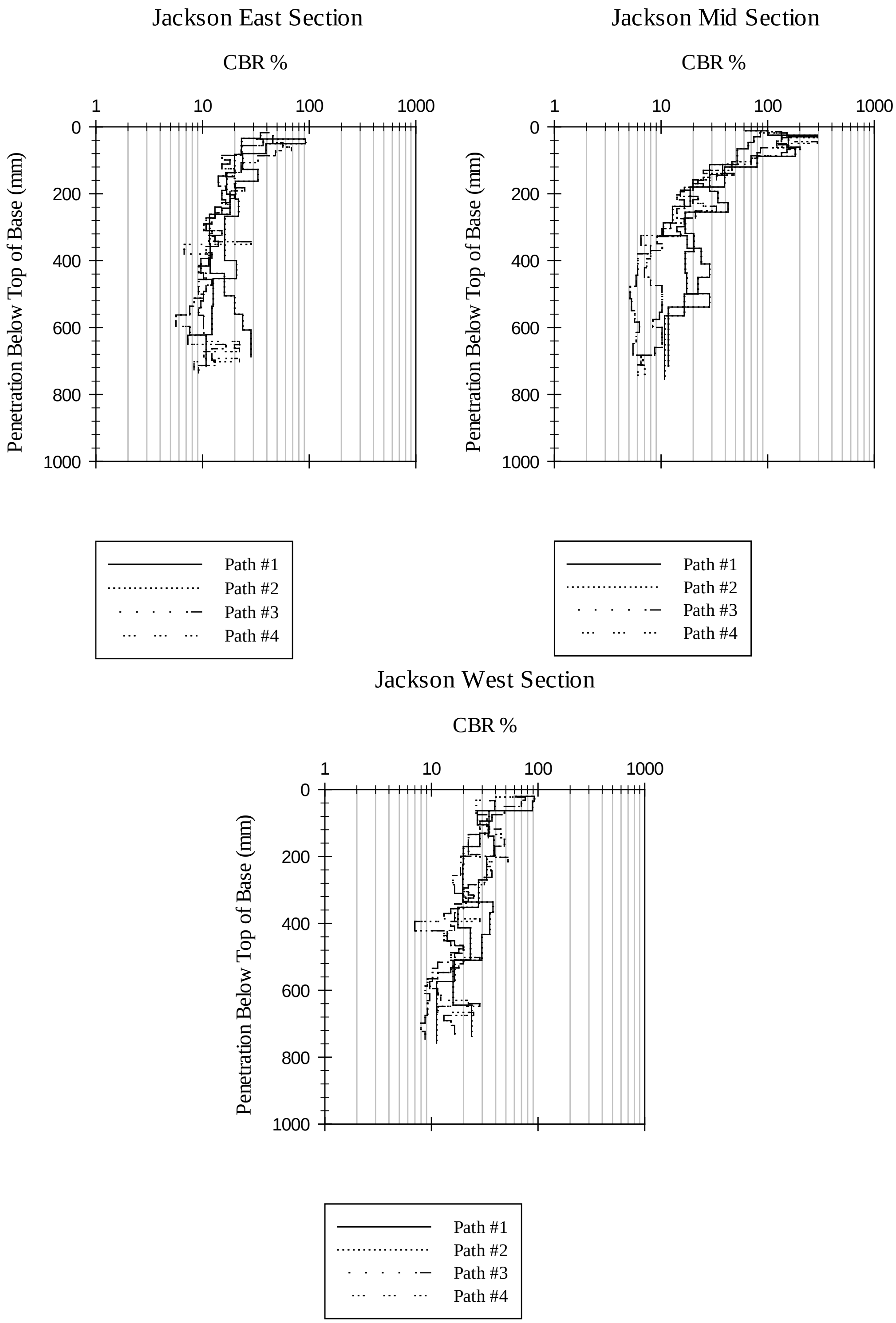


Figure 44 Cumulative Depth against CBR %-Jackson County (6/21/2014)

LWD test again shows a consistency in E-modulus readings for the three sections, as shown in Figure 31. The East Section has the highest E modulus value of 45.2MPa.

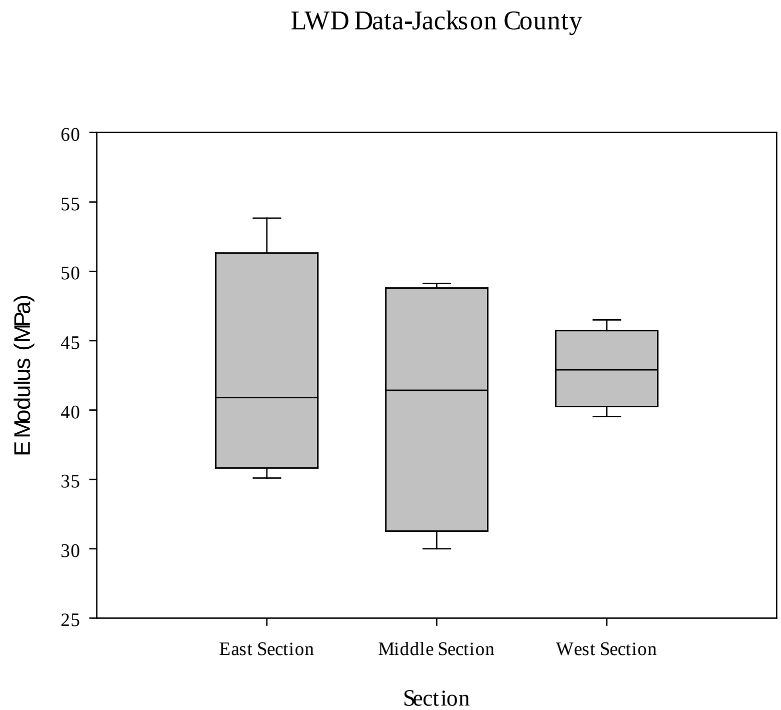


Figure 45 Boxplot of LWD Readings-Jackson County (Test Date: 6/21/2014)

Cross Section Elevation Monitor

After 9 months of service, road surface cross section profile for each section did not show a substantial change from that of the baseline which represents the cross section after construction. The average cross-sectional elevation change was -0.37ft for the East Section/3rd Section, -0.20ft for the Middle Section/2nd Section, and 0.09ft for the West Section/1st Section.

By calculating the aggregate area encompassed by the baseline profile and the average profile, potential gravel loss is possible to be estimated. The loss of gravel for the West Section/1st Section amounted to 9.8cy/mi, 75.2cy/mi for the Middle Section/2nd Section and 120.1cy/mi for the East Section/3rd Section.

Comparison analysis of multiple regression curves shows that terms related time for West Section/1st Section and Middle Section/2nd Section have coefficient of zero, meaning that no statistically difference was detected in the elevation over the observation period. The result of East Section/3rd Section, however, suggested that the elevation did change over the observation period. Further paired t test suggested that statistically significant difference was found in the elevation of the area 8 feet away from the center of the road.

Unpaved Road Condition Rating

County personnel monitored the road since the completion of construction and provided ratings of road performance. A rating chart with scoring criteria was used by the raters to assist in documenting the condition of the road on the day of the visit. Additional remarks were made to descriptively record the observation. Figure 46 shows that rutting, washboarding (corrugation) and potholes were rated as “Good” or “Very Good”, indicating a relatively low level of such distresses. For the above three distresses, the conditions were very comparable since they lie within the same severity level. For the distress of loose aggregate, however, the West Section/1st Section outperformed the other two sections. The West Section/1st Section fell in the “Good” category in terms of condition of loose aggregate. The other two sections were rated as “Fair”. In addition, for dust emission, the East Section/3rd Section was rated as “Medium”. Dust loss is the major source of material loss.

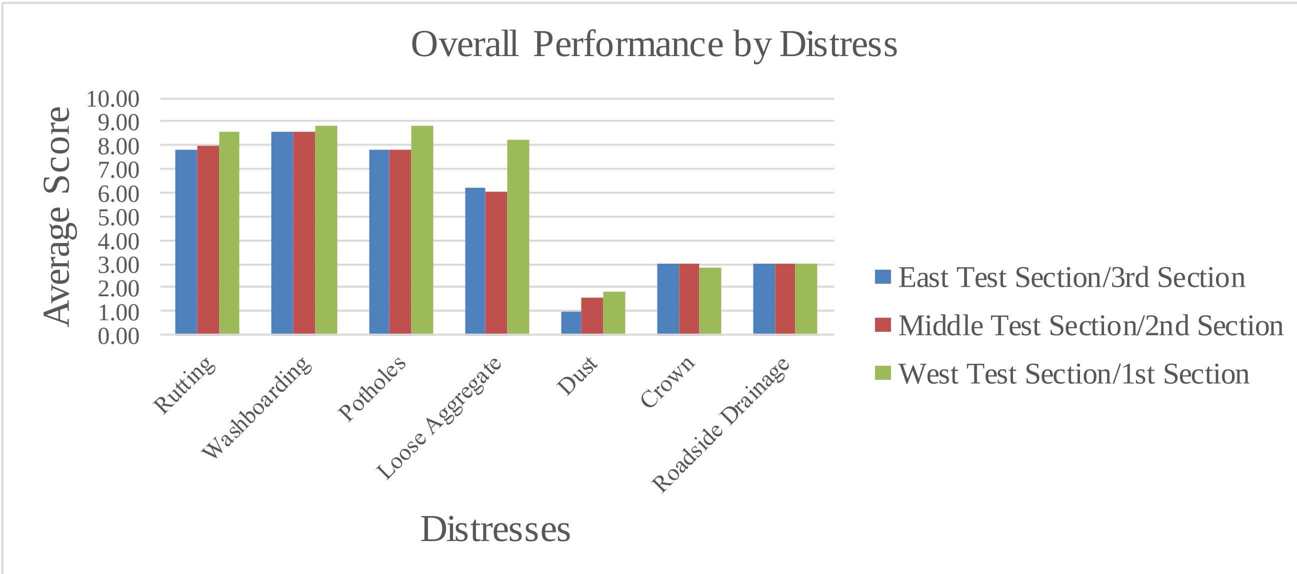


Figure 46 Pavement Condition Rating Result by Distresses-Jackson County

Overall performance rating also indicated that throughout the observation period, the West Section/1st Section outperformed the other two sections, shown in Figure 47. Necessary maintenance activities were implemented during the period of observation. Rating were carried out before the maintenance activities.

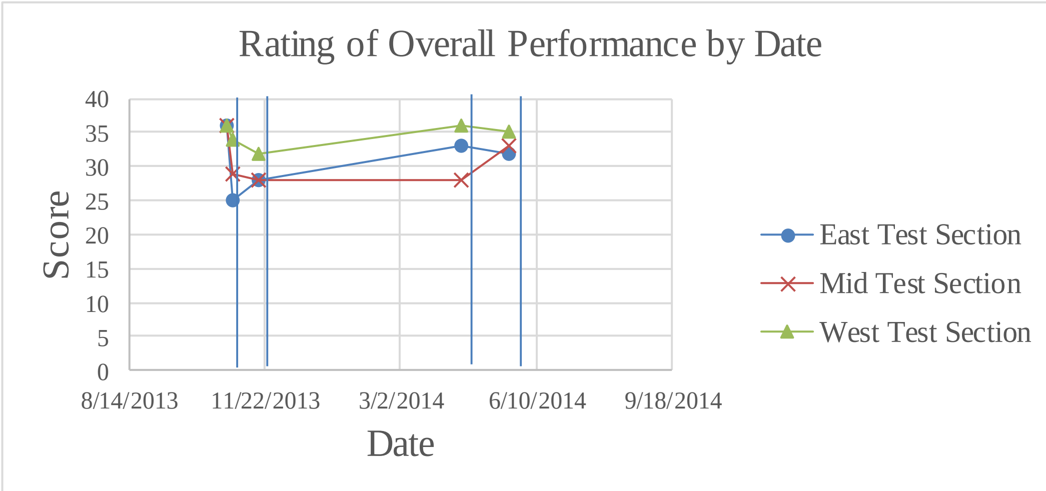


Figure 47 Pavement Condition Rating Result by Data-Jackson County[1]

Figure 48 shows that the two experimental sections suffered from loose aggregate soon after construction and the problem remained since then. Segregation resulted generated a large amount of loose aggregate that compromised the performance of the experimental sections.

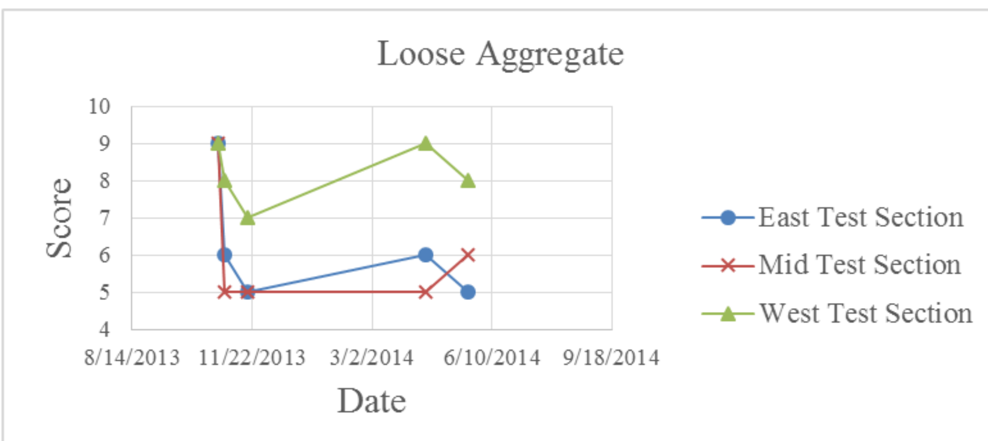


Figure 48 Rating for Loose Aggregate-Jackson County

Remarks from the county employee who served as the observer reflected his concern that the surfacing material was not binding. In the April, 2014, soon after the maintenance activities

[1] Solid lines indicate dates of maintenance activities

resumed, the county personnel could not see any trace of the crusher dust that remained in the East Section/3rd Section.

Field Observation

The first follow-up trip was made in May, 2014, approximately seven months after construction. The crusher dust mixture, which is noticeable since it has a red color, was nearly invisible. That was particularly true for the section with the least amount of crusher dust mixed in. Figure 49 shows a contrasting image of the road surface seven months after construction. Both experimental sections seemed to have failed to provide the desired performance. Seven months after construction, a scrape test result indicated an estimated 96.99 and 96.53 tons/mile of loose aggregate on the surface of Middle (12 tons of crusher dust) Section/2nd Section and East Section/3rd Section (7 tons of crusher dust), respectively, 40 percent higher than that on the surface of the control section (19 tons of Class 5 aggregate). However, a trace of crusher dust was visible in the Middle section.

Second follow-up visit was made in June, 2014. No more follow-up visits were made to Jackson County since the crusher dust mixture under these conditions did not appear to be providing the desired result.

Figure 49 Seven Months after Construction-Jackson County

BELTRAMI COUNTY

Material Properties

The addition of crusher dust successfully boosted the fine content of the in-situ loose aggregate on the surface, see Figure 50. The north Section has the highest fine content among the three sections.

Detailed material properties are summarized in Table 9. Unlike the resulting material in Jackson County, the resulting material in Beltrami County contains clayey soil which possesses some binding capacity. Although the plasticity index does not seem to be within the typical range recommended by the specification, the road surface in Beltrami County constructed with the plastic material provides a better, smoother surface in comparison to that of Jackson County.

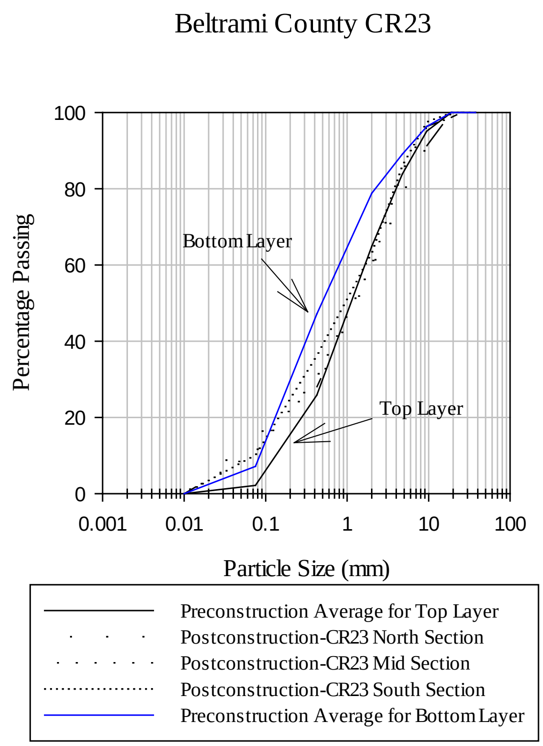


Figure 50 PSD of Material-Beltrami County CR 23

Table 9 Detailed Material Properties after Mixed in-Beltrami CR 23

Beltrami County									
Sieve Size	Percentage Passing			Percentage Passing			Percentage Passing		
	North CR23		Average	Mid CR23		Average	South CR23		Average
	#1	#2		#1	#2		#1	#2	
1.5"	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
1"	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3/4"	98.4%	100.0%	99.2%	100.0%	99.1%	99.6%	100.0%	100.0%	100.0%
3/8"	96.5%	91.5%	94.0%	97.9%	96.3%	97.1%	97.2%	97.9%	97.6%
#4	84.9%	78.2%	81.5%	87.1%	84.9%	86.0%	85.4%	87.1%	86.2%
#8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
#10	59.9%	59.0%	59.4%	64.9%	60.4%	62.7%	61.9%	64.9%	63.4%
#30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
#40	30.6%	28.3%	29.5%	37.6%	30.8%	34.2%	35.2%	37.6%	36.4%
#100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
#200	10.9%	15.4%	13.1%	10.5%	11.2%	10.8%	10.0%	10.5%	10.2%
<#200	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Liquid Limit	17.0%			17.0%			17.0%		
Plastic Limit	13.6%			14.3%			15.6%		
Plastic Index	4.00			3.00			2.00		

DCP and LWD Test

From the Penetration-Cumulative Blows plots, Figure 51, it is apparent that the various layers of road surface and subgrade material are consistent with regard to stability because the penetration per blow is relatively constant. Penetration-CBR plots, Figure 52, show CBR value for the each section along the depth of the pavement. The CBR value for the top 200 mm has an average value of 46.18 for the north section/1st Section, 40.26 for the Middle Section/2nd Section and 50.26 for the South Section/3rd Section.

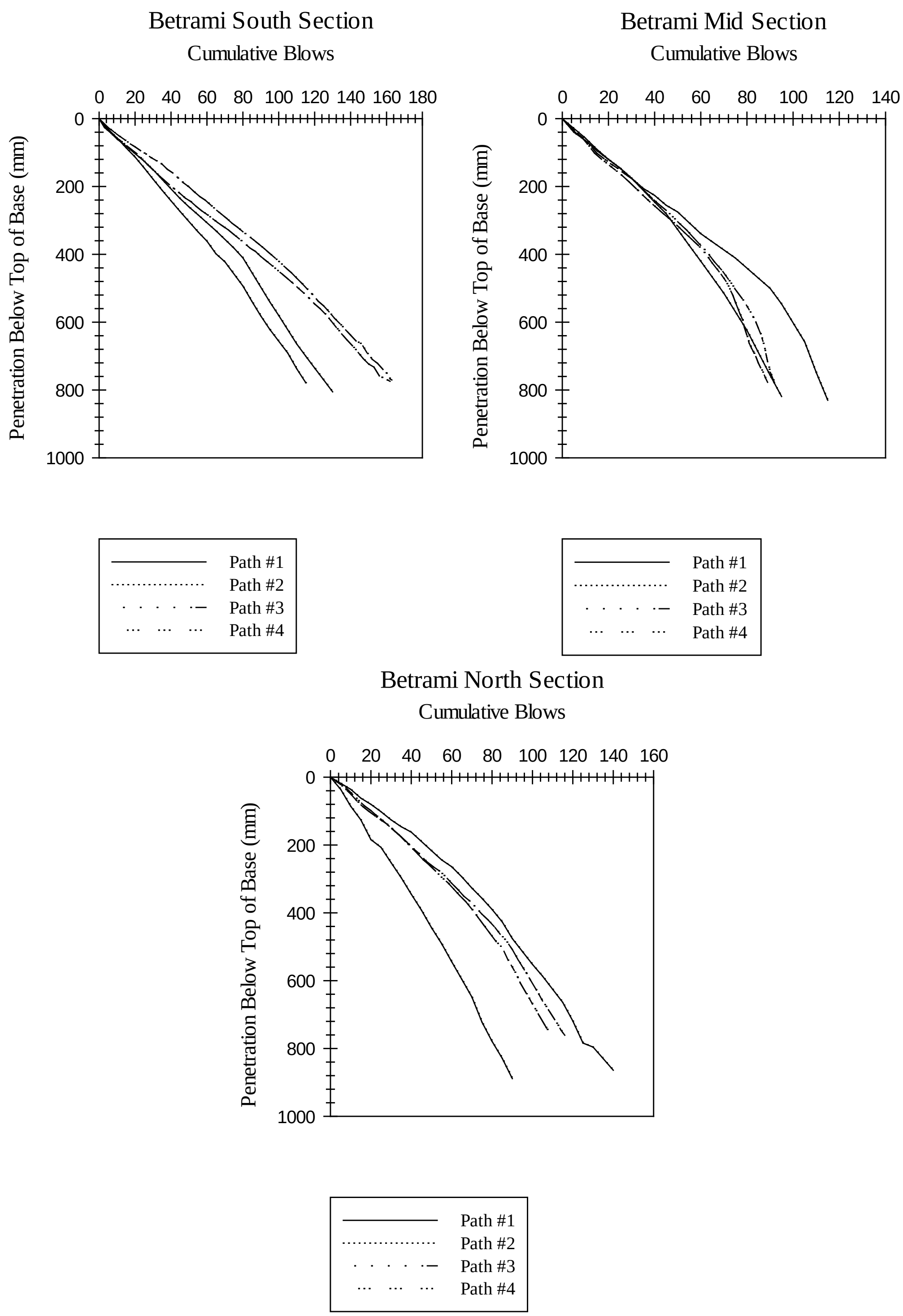


Figure 51 Cumulative Depth against Cumulative Blow - Beltrami County (6/22/2014)

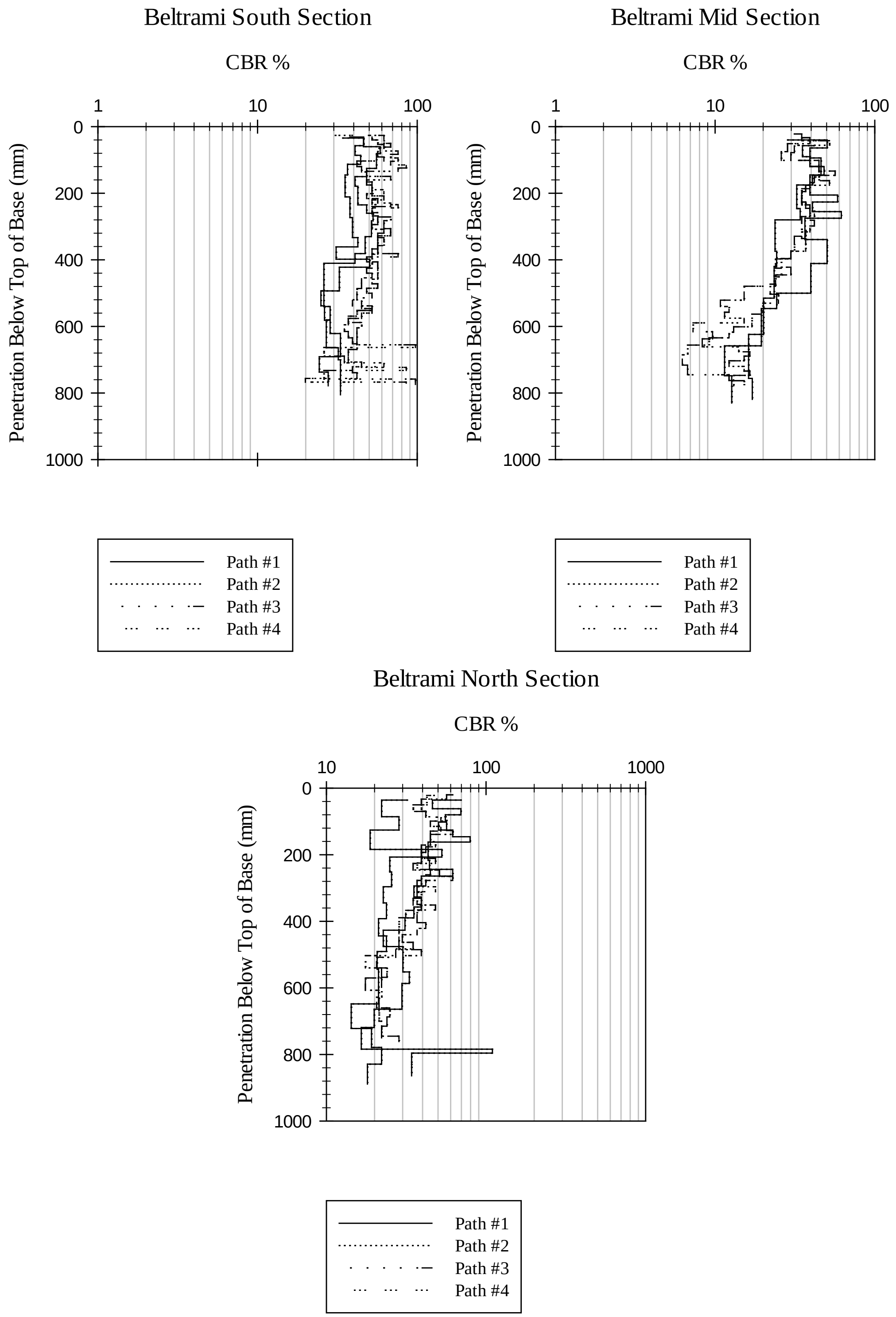


Figure 52 Cumulative Depth against CBR %-Beltrami County (6/22/2014)

LWD data shows comparable stiffness across test sections as Figure 53 shows that data in the range between 25th and 75th percentile overlaps.

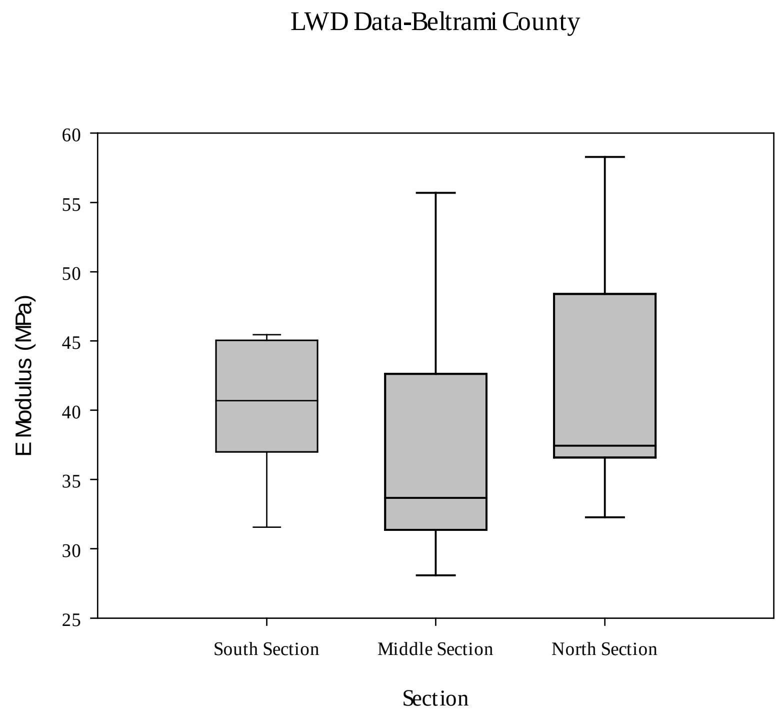


Figure 53 Boxplot of LWD Readings-Beltrami County (Test Date: 6/22/2014)

Cross Section Elevation Monitor

During the 8 months of service, the average elevation change had been very almost unnoticeable. The North Section/1st Section had -0.05 ft of elevation change. -0.06 ft for the Middle Section/2nd Section and -0.09 ft for the South Section/3rd Section. In Comparison to the three test sections in Jackson County, the road surfaces in Beltrami County performed better maintained, most likely because of the surfacing material that resulted from the mixing process had a relatively higher plasticity in comparison to that of Jackson County.

The estimated amount of gravel loss for the north Section/1st Section was 20.2 cy, the Middle Section/2nd Section 24.7 cy/mi and the South Section/3rd Section 35.2 cy/mi according to calculations based on cross section data.

Regression analysis was performed and the results indicated that that no statistically significant difference was found in any one of the three test sections for Beltrami County.

Unpaved Road Condition Rating

The South Section/3rd Section was rated "Fair" for the distress of washboarding, which reflects the lasting distress observed in this section. Fair level of washboarding suggests that 10%-25% of roadway appears to suffer from corrugations that are generally 1"-2" deep and vehicle control is compromised. The Middle Section/2nd Section particularly performed well by having few pothole distress. See Figure 54 below.

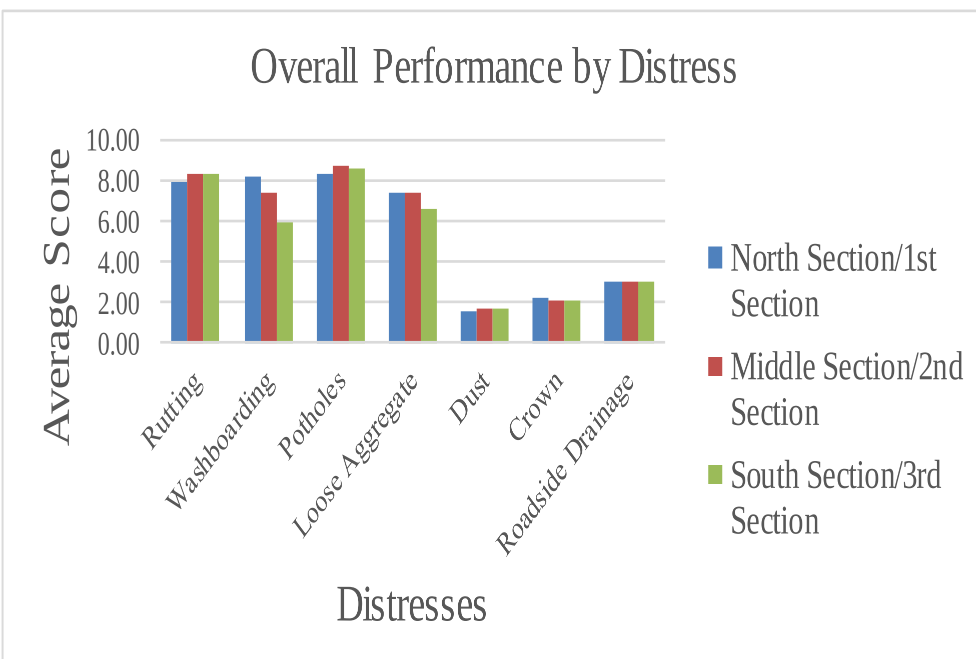


Figure 54 Pavement Condition Rating Result by Distresses-Beltrami County

Considering that the scores assigned to the distresses of dust, crown and roadside drainage were very close, if not exactly the same, the overall performance according to the rating would be highly depending on the rest of the distresses that have not been previously mentioned in this sentence. Figure 55 shows that even though the north Section/1st Section were assigned the highest scores at the beginning of the observation period, the Middle Section/2nd Section caught up later in time. This can most likely be attributed to the relatively good performance in terms of rutting and potholes. The South Section/3rd Section remained at the lowest score level for the majority of the observation period, even though that the south section/3rd section received higher frequency of maintenance activity.

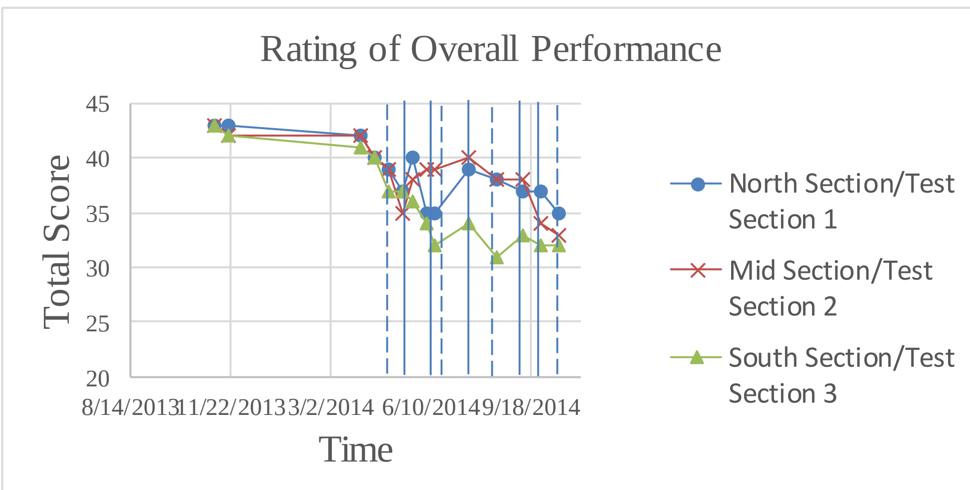


Figure 55 Pavement Condition Rating Result by Date-Beltrami County[2]

The South Section/3rd Section started to deteriorate noticeably beginning in late May as it was entering into a dryer summer season. The deterioration is most pronounced in terms of washboarding, Figure 56.

[2] Solid lines indicate dates of maintenance activities that were carried out for all sections. Dashed lines indicate dates of maintenance activities that were carried out on certain sections.

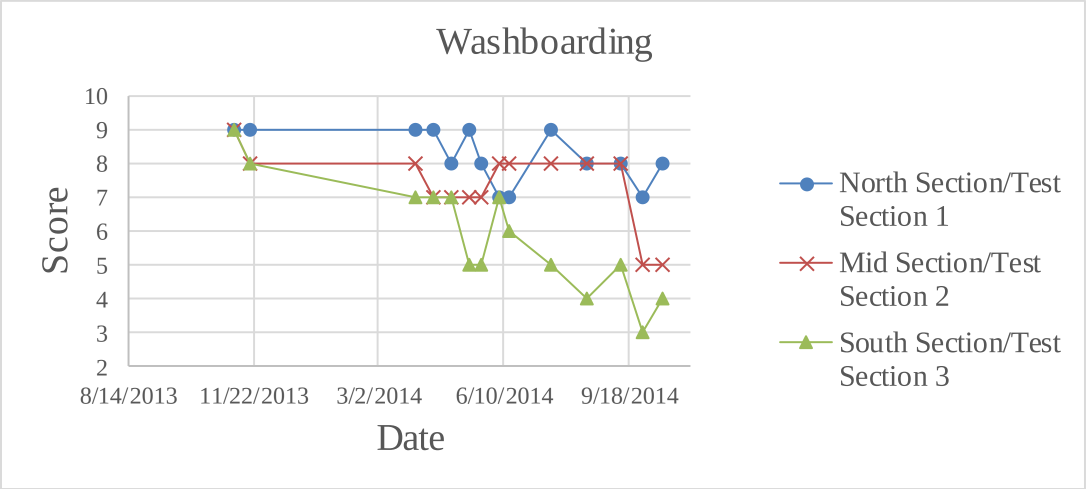


Figure 56 Rating for Washboarding-Beltrami County

Loose aggregate issues started to occur in May as well, and were the worst for the South Section/3rd Section, Figure 57.

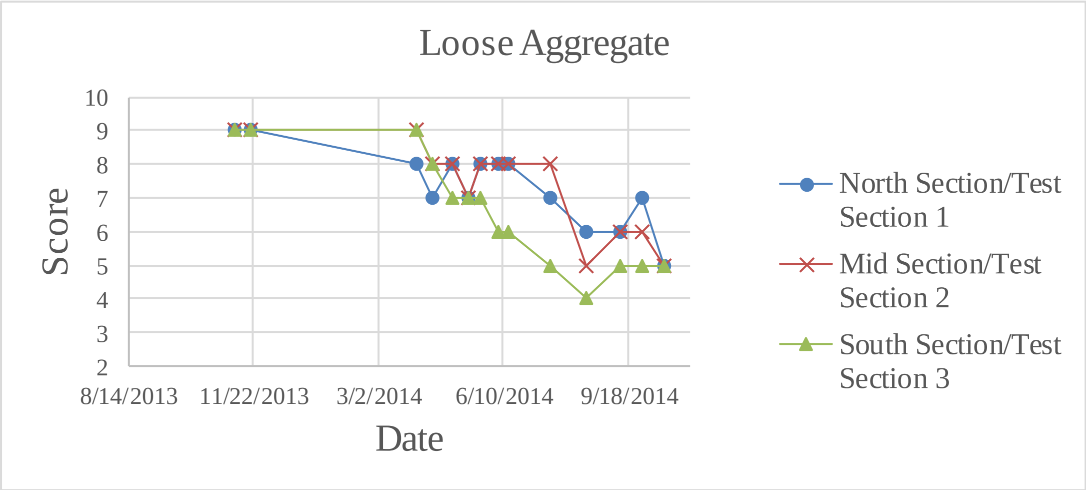


Figure 57 Rating for Loose Aggregate-Beltrami County

It is of interest to reveal how all the sections were performing during the dry season, in this case, after late May; this can be done by examining distress in detail. Figure 58 shows that the ratings for washboarding and loose aggregate for the South Section/3rd Section have dropped substantially,

Figure 54, while the ratings for both the North Section/1st Section and Middle Section/2nd Section exhibit a noticeably less substantial drop.

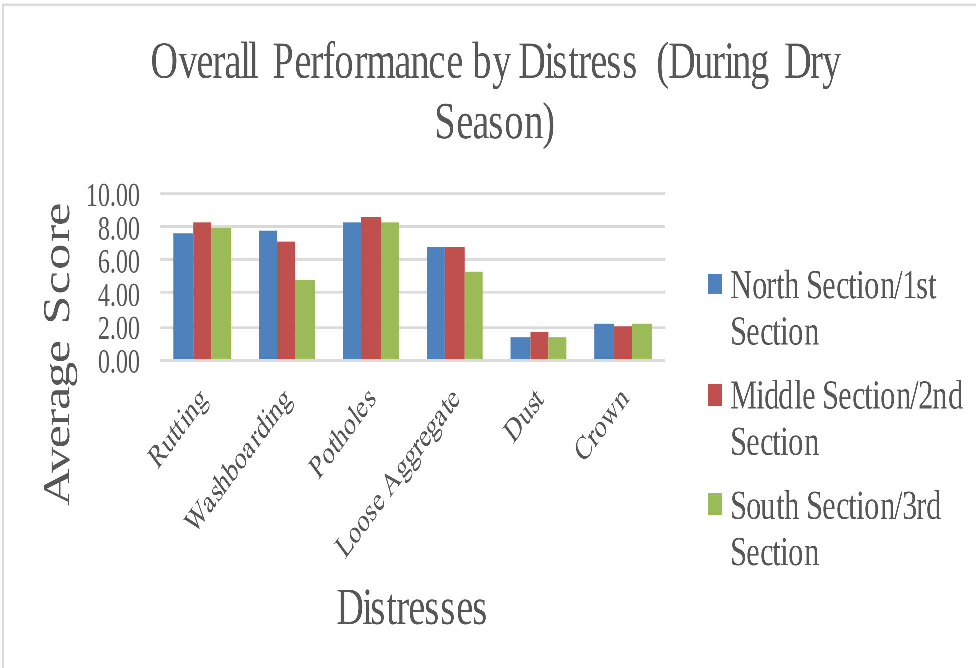


Figure 58 Overall Rating by Distress during Dry Season-Beltrami County

Remarks made by the maintenance supervisor who was in charge of this rating activity reflected that he was generally satisfied with the outcome from the two experimental sections. Although he admitted that there had been some improvement by mixing in crusher dust for the South Section/3rd Section, the corrugation formed reduced its serviceability in a more noticeable way. He supposed the traffic volume might differ for the South Section/3rd Section because the intersection with CR 110 is between that south and middle test sections. This will be discussed in later.

The Middle Section/2nd Section generally met expectations; that is it was presumed that the higher volume of crusher dust perhaps would be beneficial. The performance is comparable to the North

Section/1st Section, although the person performing the rating personally favored the performance of the north Section/1st Section.

Estimated International Roughness Index

Roadroid generated estimated IRI as shown in Figure 59. From the graph, although it appears that some segments of the north Section/1st Section and the Middle Section/2nd Section were rougher than the rest of the road, the three test sections generally provide a good riding quality as the estimated IRI is smaller than 2.2.

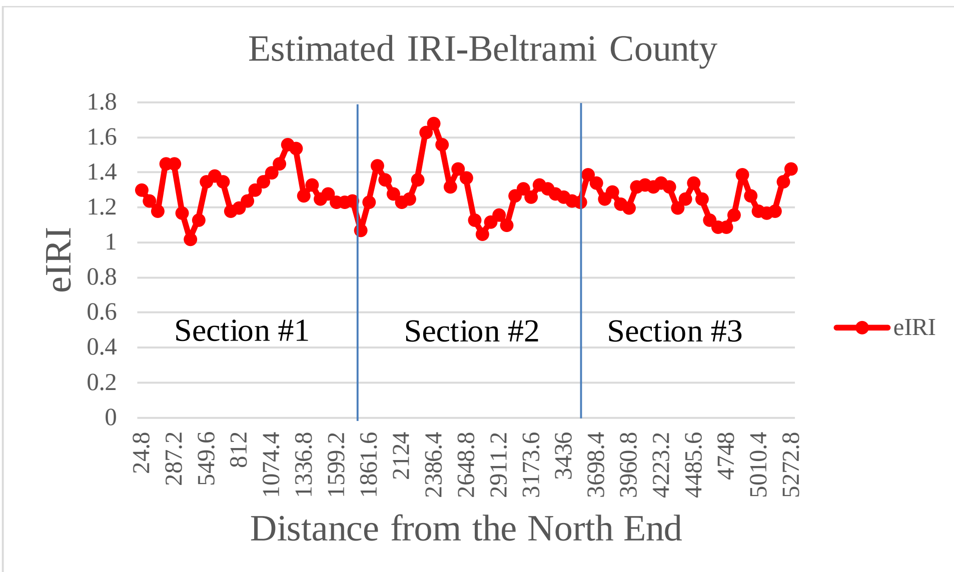


Figure 59 Estimated IRI-Beltrami County[3]

Field Observation

The first follow-up visit was made in May 23rd, 2014, approximately six months after construction. The north Section/1st Section (166 tons of crusher dust) and Middle Section/2nd Section (83 tons of crusher dust) were holding up in a satisfactory manner.

[3] Solid lines indicate the boundary of test sections

Figure 60 North Section (Left) and Middle Section (Right) (Photo by the Author)

The more lightly colored areas indicates that the area is more highly compacted, see Figure 60. The larger the lighter area was, the lower the amount of loose aggregate that remained on the surface. It turned out that in the South Section/3rd Section, the loose aggregate was estimated to be 59 tons, 24 percent higher than that on the surface of the North Section/1st Section.

Figure 61 Typical Corrugation in the South Section/3rd Section (Photo by the Author)

Corrugation appeared throughout the South Section/3rd Section, see Figure 61. The depth of corrugation was approximately ½ in; meanwhile corrugations did not form on the two other test sections. To further investigate if differences in traffic volume contributed to the difference in performance, a four-hour traffic count was performed by of Beltrami County Highway Department personnel. Figure 62 indicates the location of traffic count as well as the three test sections. The result revealed that South Section/3rd Section serving 17 vehicles while the Middle Section/2nd Section and the north Section/2nd Section were serving 18 vehicles. The fair performance of the South Section/3rd Section was attributed to the lower amount of crusher dust that was mixed in as binder in comparison to Middle Section/2nd Section, slight corrugation was seen near the intersection. No corrugation was seen in the North Section/1st Section.

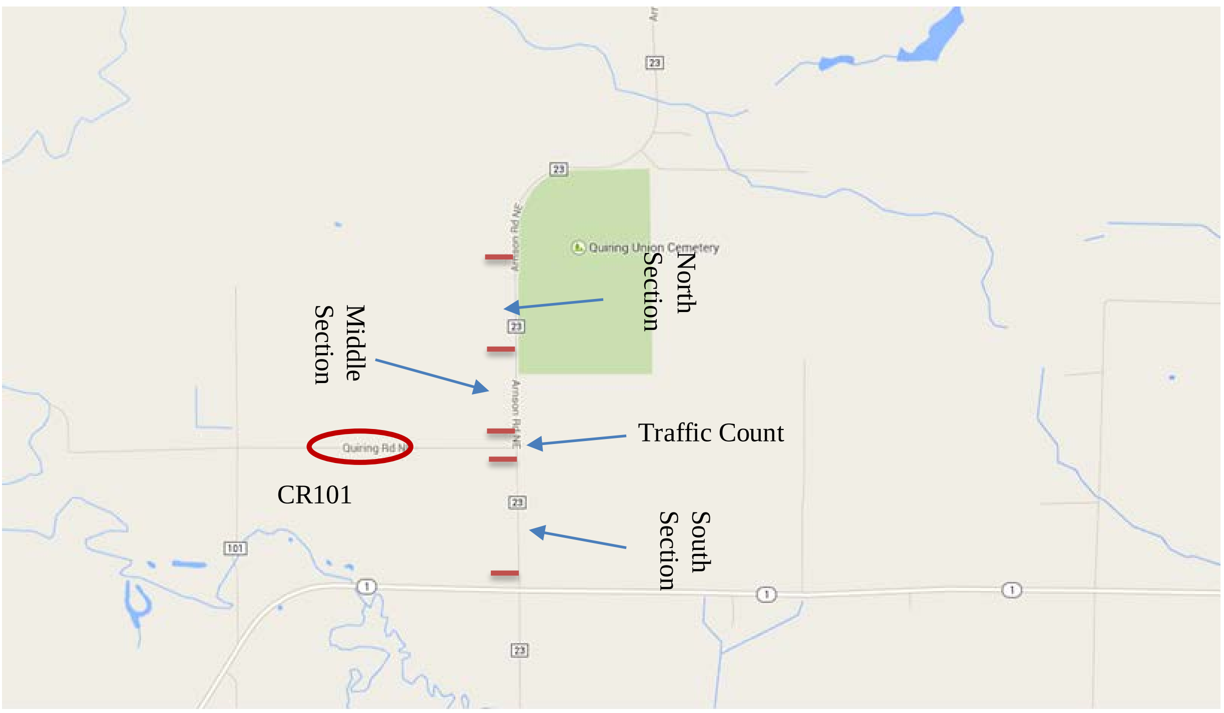


Figure 62 Traffic Count Location

OLMSTED COUNTY

Objective of the Test Section in Olmsted County

Limestone is a major source of surfacing aggregate for the unpaved roads in the area. Class 2 specified gradation has been adopted for the aggregate used for this purpose. From the past experience, the Class 2 specification aggregate that was used for wearing surface gradually became finer over the time of service. The use of Class 5 specification aggregate, on the contrary, led to too many “marbles” as floating loose aggregate particles were described informally by county personnel. Olmsted County proposed to construct trial test sections to test sections using a 1:1 mix of the Class 2 and Class 5 aggregate and a 1:2 mix of Class 5 aggregate and lime. Lime is the terminology used to describe the fines that result from the limestone crushing process.

Therefore, the project had two control sections, being Sections 1 and 4, and two experimental sections, being Sections 2 and 3.In total, four test sections were established. Recall that the test sections on County Road 115 were not laid out continuously, as shown in Figure 40. Section 1 and 2 were located at the south end of CR 115 and sections 3 and 4 were located at the north end of CR 115.

Material Properties

PSD plots are shown in Figure 63. It is interesting to note that the resulting gradation of the newly placed material was coarser than that of the top material. All material was determined to non-plastic as shown in Table 10.

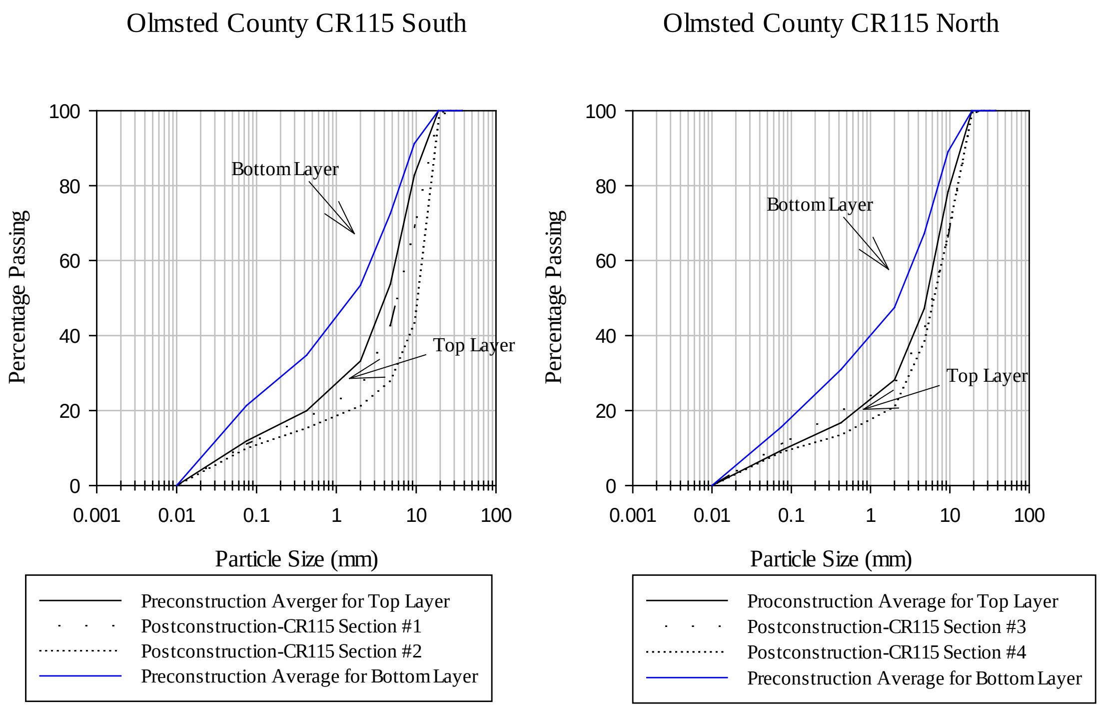


Figure 63 PSD of Material-Olmsted County CR 115

Table 10 Detailed Material Properties after Mixed in-Olmsted CR 115

Olmsted County												
Sieve Size	Percentage Passing			Percentage Passing			Percentage Passing			Percentage Passing		
	CR115 Section 1		Average	CR115 Section 2		Average	CR115 Section 3		Average	CR115 Section 4		Average
	#1	#2		#1	#2		#1	#2		#1	#2	
1.5"	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
1"	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3/4"	99.6%	99.2%	99.4%	97.3%	98.7%	98.0%	99.3%	99.1%	99.2%	99.7%	99.3%	99.5%
3/8"	62.9%	74.2%	68.5%	46.8%	40.4%	43.6%	66.1%	66.6%	66.3%	60.9%	71.2%	66.1%
#4	37.9%	47.4%	42.7%	30.6%	25.5%	28.0%	41.1%	42.2%	41.7%	34.3%	41.0%	37.7%
#8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
#10	24.2%	28.1%	26.2%	23.0%	19.6%	21.3%	27.0%	27.5%	27.3%	19.1%	22.2%	20.6%
#30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
#40	17.0%	18.9%	17.9%	15.5%	15.1%	15.3%	19.8%	20.2%	20.0%	11.7%	14.7%	13.2%
#100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
#200	10.7%	11.3%	11.0%	9.0%	10.8%	9.9%	10.9%	11.2%	11.1%	8.5%	9.2%	8.8%
<#200	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Liquid Limit	15.4%			17.1%			15.6%			14.1%		
Plastic Limit	16.4%			16.7%			16.2%			15.1%		
Plastic Index	0.00			0.00			0.00			0.00		

DCP and LWD Test

Figure 64 shows a clear indication of the location of the interface between crushed rock layer and subgrade layer. The crushed rock of test sections had various depths ranging from 200mm (7.9 inches) to 300mm (11.8 inches). Figure 65 shows comparable CBR value that is close or higher than 200 within the gravel layer.

Figure 66 shows comparable LWD readings. In other words, no noticeable difference was discovered in the stiffness of the road surfacing materials for the four test sections.

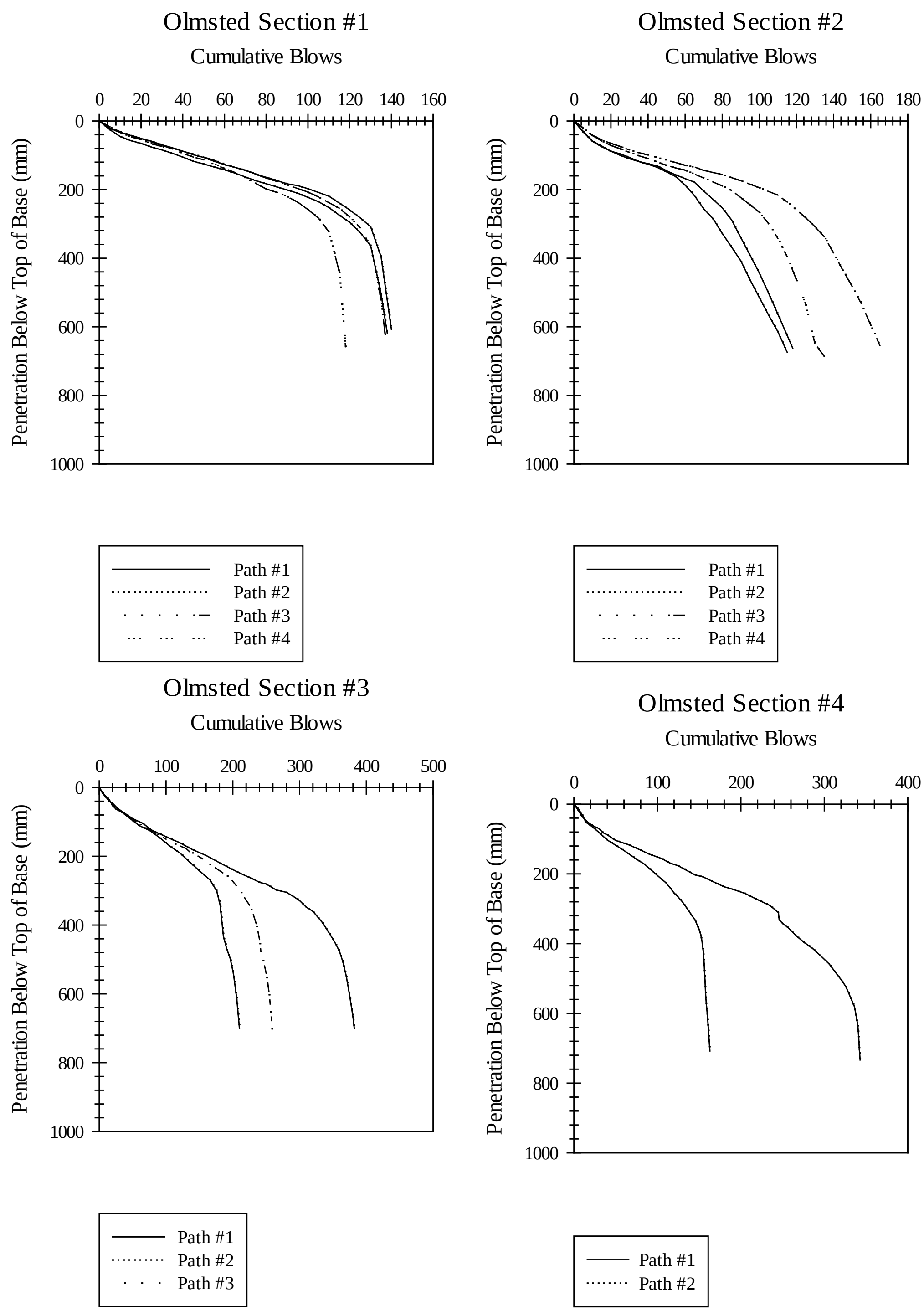


Figure 64 Cumulative Depth against Cumulative Blow-Olmsted County (6/20/2014)

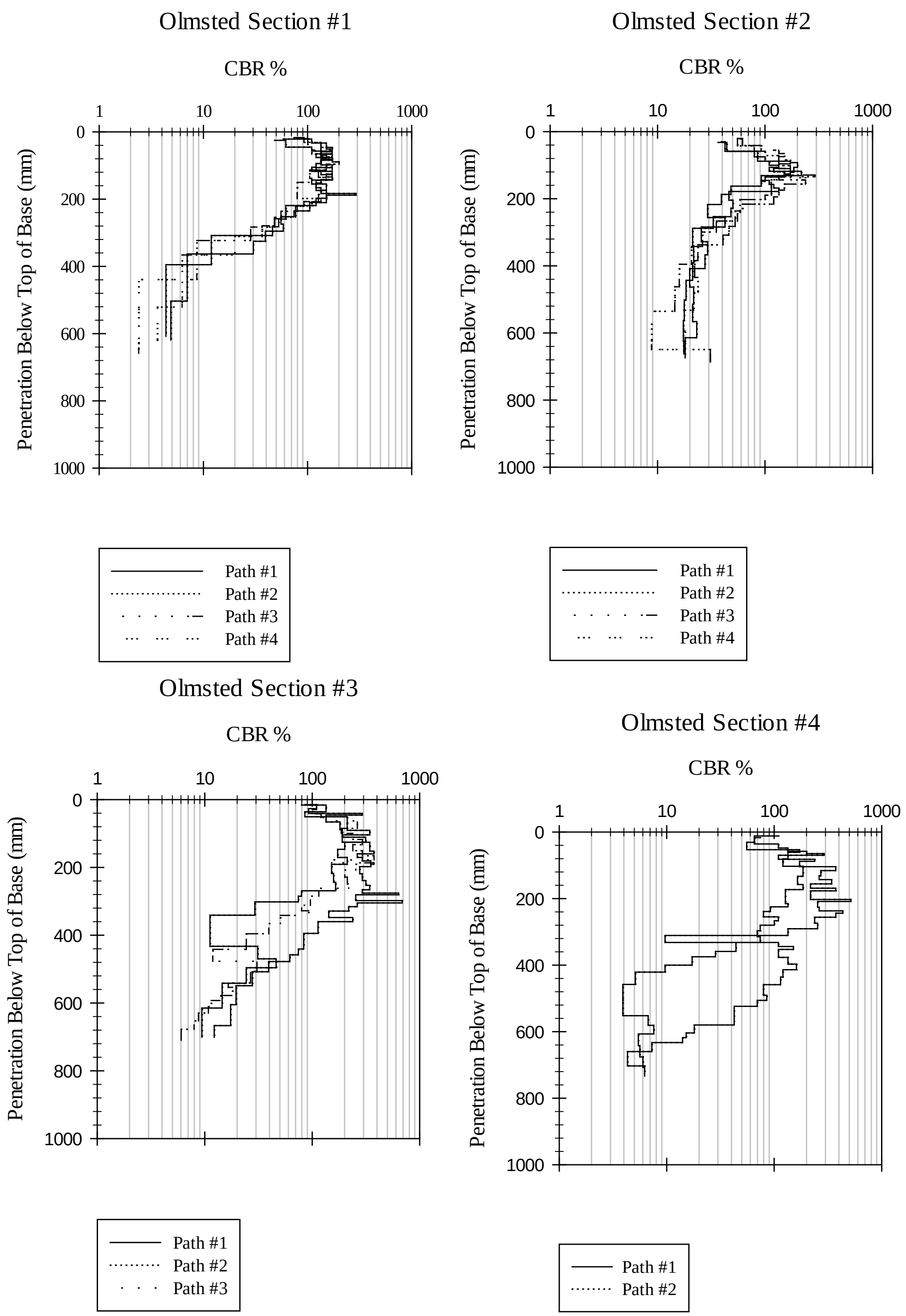


Figure 65 Cumulative Depth against CBR %-Olmsted County (6/20/2014)

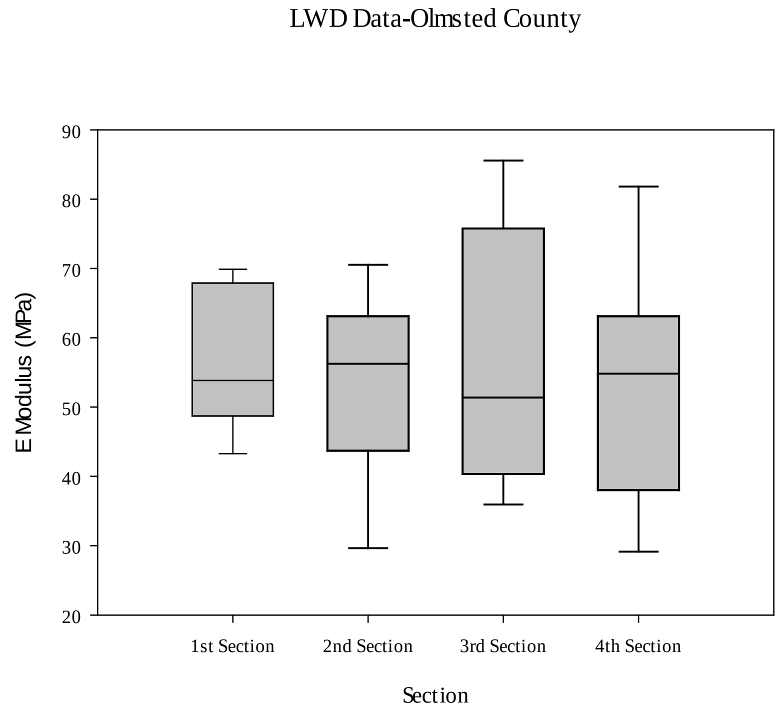


Figure 66 LWD Readings-Olmsted County (6/20/2014)

Cross Section Elevation Monitor

After 12 months service, the road surface was still well maintained with good crown to shed water. There was some rutting but not a substantial amount. Since the aggregate used to build the road was non-plastic, gravel loss could be substantial due to the fact that fugitive dust emission would be expected to be generally high since no dust control actions were taken. Both control sections, Section 1 and 4, had an average elevation decrease of 0.19 ft and 0.28 ft respectively. Section 2 and 3 experienced elevation decreases of 0.24ft and 0.1ft respectively.

The gravel loss for the 1st section was estimated to be up to 86 cy/mi, the 2nd section was estimated to be 104.2 cy/mi, 3rd section was estimated to be 65.8 cy/mi and the 4th section was estimated to be 93.8 cy/mi.

Regression analysis revealed that the 4th Section experienced statistically significant elevation change during the observation period. Further paired t test suggested that the south bound lane of the test section experienced larger elevation loss.

Unpaved Road Condition Rating

All four test sections were considered to be performing reasonably well, except that Section 1 received rating of "Fair" with respect to loose aggregate while the other sections were rated "Good". In addition, Section 1 had more severe corrugation in comparison to the other sections, probably due to the proximity to an intersection. Figure 51 shows the rating result by distress

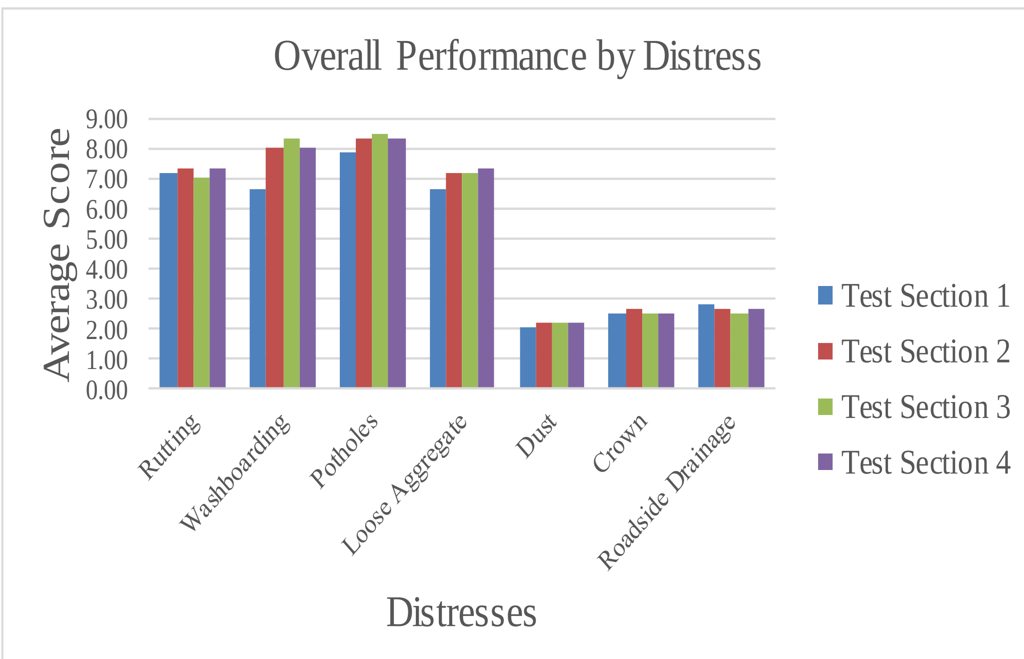


Figure 67 Pavement Condition Rating Result by Distresses-Beltrami County

Considering that same score was given to distresses of dust, crown and roadside drainage, differences in the overall rating must be due to difference is distress rating not previously mentioned in this sentence. Figure 68 shows the rating outcomes by date. The sudden jump resulted from the addition of the distress of washboarding. Washboarding was not expected to be problematic, since the test sections were located some distance away from intersections. During dry season, there was not a significant difference in performance among sections.

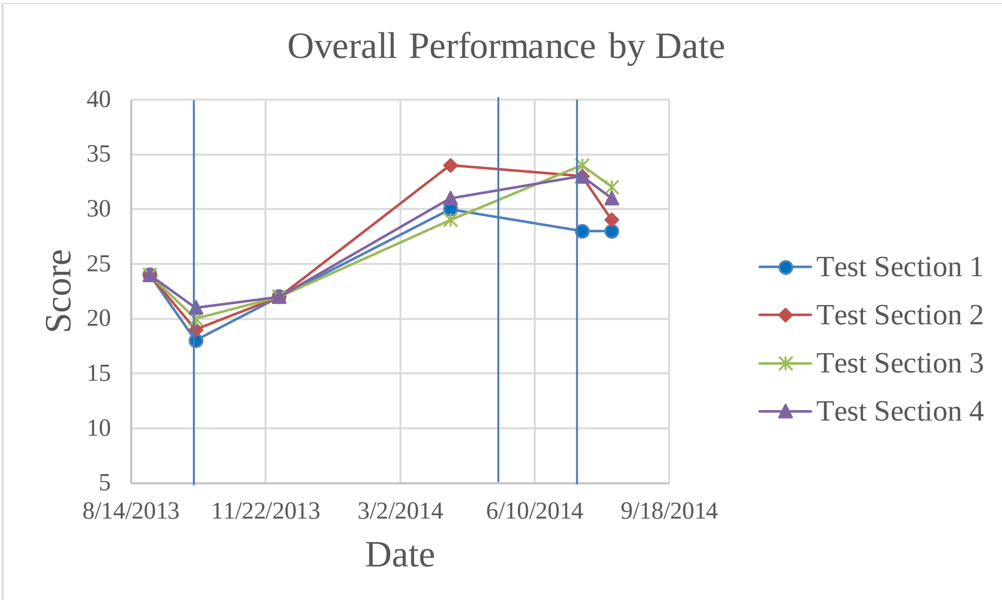


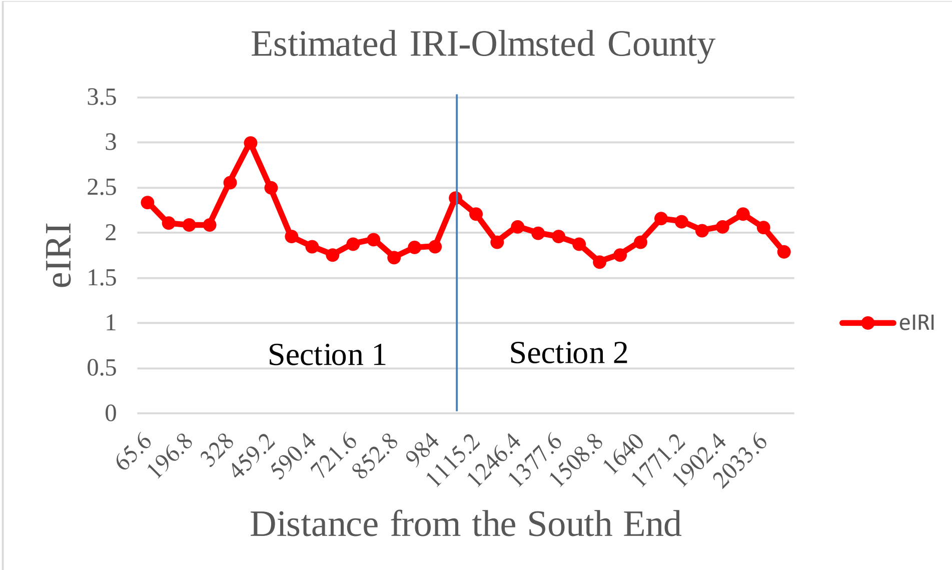
Figure 68 Pavement Condition Rating Result by Data-Jackson[4] County

Remarks made by the maintenance supervisor was positive. He expressed that the sections were holding up very well. The only major problems that he reported during several email exchanges was that there was noticeable higher amount of loose aggregate on the surface of Section 1.

Estimated International Roughness Index

There were spikes in the roughness measurements for Section 1 and 3 for a short distance. Otherwise, all four sections had stable eIRI value. Generally, they provided a good riding surface as the average eIRI value for each section was smaller than 2.2.

[4] Solid lines indicate dates of maintenance activities



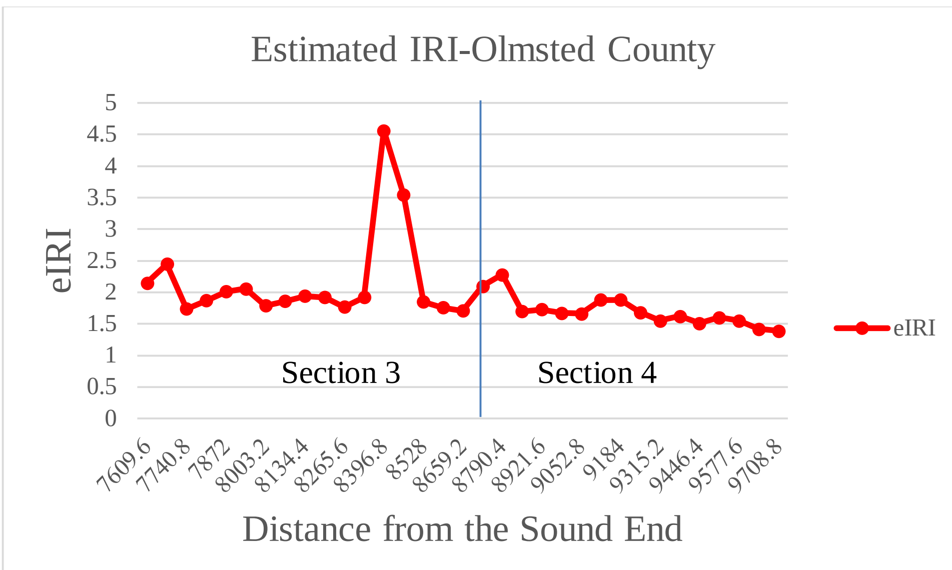


Figure 69 Estimated IRI-Olmsted County[5]

Field Observation

The first follow-up visit was approximately 8 months after the construction completed. Overall, all four sections were holding up satisfactorily since. There had been two grading maintenance action implemented from May through August. Desired crown for effective water shedding was

[5] Solid lines indicate the boundary of test sections

remained throughout the period. Clear wheel paths were exposed for Sections 2, 3, and 4 which provided a firm and smooth driving surface, seen in Figure 70.

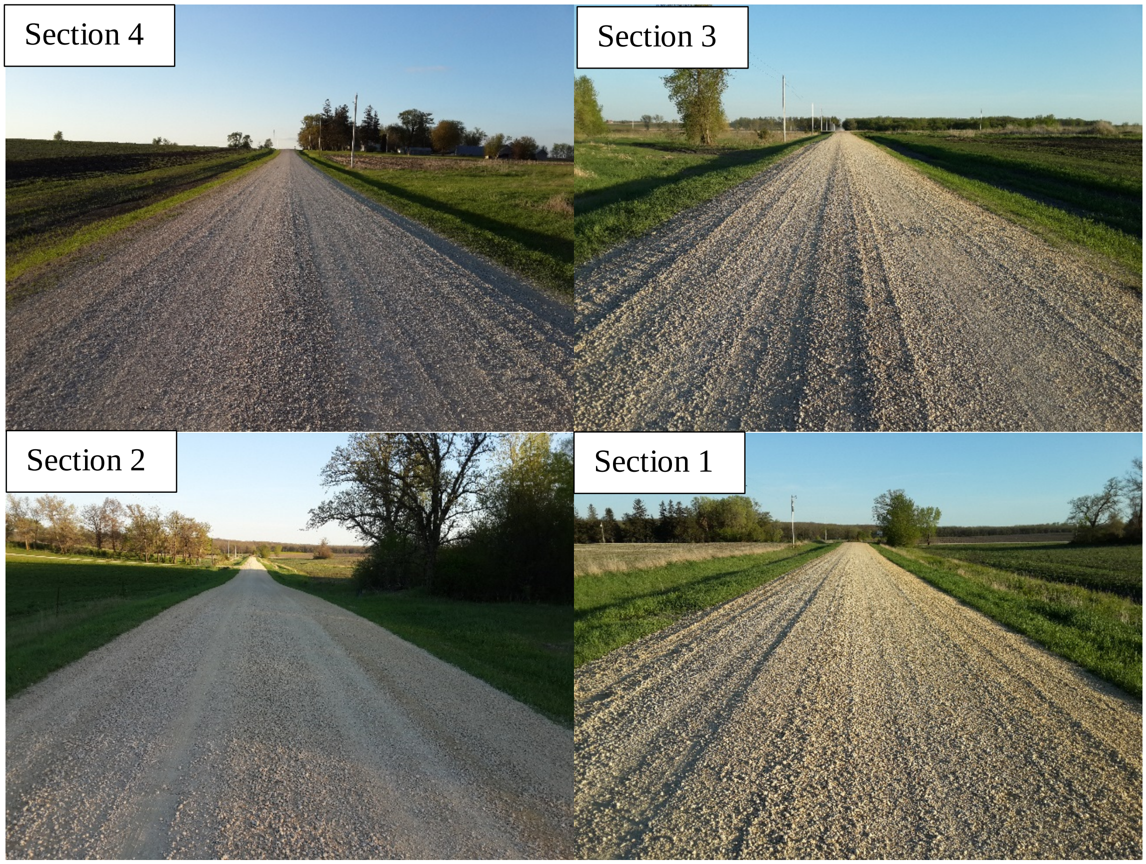


Figure 70 Four Test Sections Surface-Olmsted County CR 115 (Photo by the Author)

There was relatively little loose aggregate on the surface of Sections 2, 3, and 4. However, there was relatively more loose aggregate was observed in Section 1, to an extent that the riding quality was compromised.

Figure 71 Loose Aggregate on the Surface of Section 1

The visual observation was in line with the results of the scrape tests which revealed that the amount of loose aggregate was higher for Section 1 in comparison to than the rest by 15 percent.

CHAPTER SUMMARY

This chapter discussed about the material composition difference between the top and the bottom layers and the performance assessment conducted in the three counties that participated in test section construction.

The investigation regarding the difference between the top and bottom layers of road surfacing material revealed that the top layer is in lacking in the proportion of particles of the size of No. #4 (4.75mm) and smaller. The shortfall becomes larger as the particle size becomes smaller. The bottom material is 3.6 times the proportion of No. 200 fines in comparison to the top material.

The test sections demonstrated that by mixing crusher dust, it is possible to rejuvenate the aggregate surface if several points below are given consideration.

- The resulting mixture apparently needs to have some binding capacity if the existing aggregate is non-plastic. The lack of improvement experienced with test sections in Jackson County appears to be mainly attributable to the non-plasticity of both the resulting mixture. This might suggest that if the crusher dust and the original aggregates is non-plastic, adding crusher dust without any other additives that help stabilize would not be able to rejuvenate the aggregate surface.

- The amount of fine material added also appears to be important. An inadequate amount of added fine material appears to have led ineffective rejuvenation effort that Jackson County experienced. Given current knowledge, empirical judgment seems to be necessary to estimate the required amount of fine material to add. Calculated conducted by the research team based on analysis of the gradation of the top and the bottom material did not produce the desired results in Jackson County. Based on the advice of the Beltrami County maintenance supervisor, the amount of added aggregate was increased in comparison to the amount that the researchers recommended based on the calculations. By having a greater amount of fine material, (crusher dust in this case) in the mixing process was more successful in Beltrami County in comparison to that in Jackson County with a lesser amount of fine material.

In Jackson County, the experimental sections did not perform up to expectation. Results from collected data indicated that the control section performed better than the experimental sections.

In Beltrami County, the South Section/3rd Section did not perform as well as the Middle Section/2nd Section, whose performance was comparable to the North Section/1st Section. The Middle Section/2nd Section might have the best performance. The reduction in the upfront cost is considered as a positive performance attribute. Cost-benefit analysis was performed in the following chapter.

All four test sections in Olmsted County provided excellent performance according to the rating system adopted by this investigation during the period of observation. Collected data shows a comparable performance among the four sections. Nevertheless, the 4th Section/North Section experienced some cross section deterioration. The volume of loose aggregate on the surface of the 1st Section was of concern since the excessive loose aggregate could compromise driving safety.

In terms of road roughness, all sections in Beltrami and Olmsted that were assessed with the Roadroid turn out to be within the "Good" category, suggesting at least adequate riding quality".

Amount of floating aggregate and gravel loss after construction estimated for each test section is presented below.

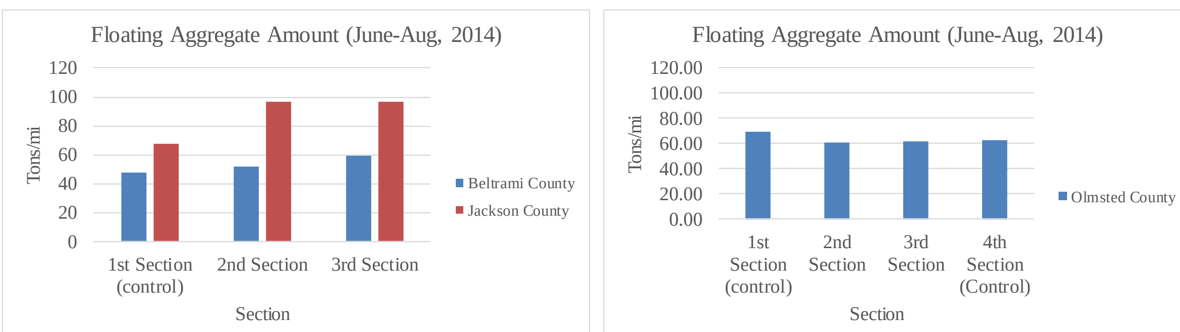


Figure 72 Floating Aggregate Amount

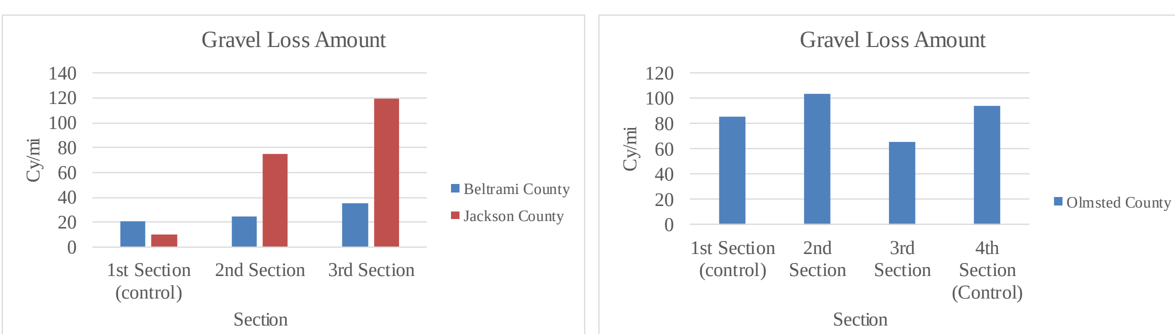
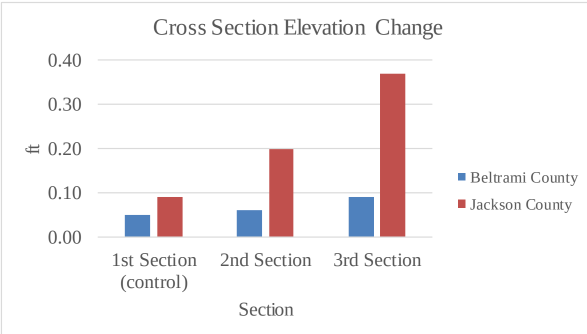


Figure 73 Gravel Loss Amount



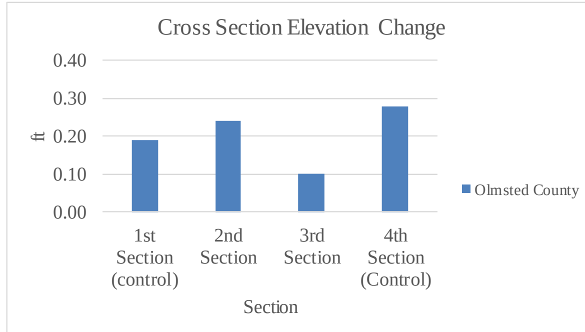


Figure 74 Cross Section Elevation Decrease

CHAPTER 5: ECONOMIC ANALYSIS

To meet one of the objectives of this research, economic analyses were conducted. The research team collected cost data from highway departments of participating counties. The objective of the economic analysis is to determine whether or not the concept of aggregate rejuvenation is economically feasible on the premise that serviceability is not compromised.

COST COMPARISON ANALYSIS

A cost comparisons were performed regarding the upfront cost to assess the cost effectiveness of adopting the aggregate rejuvenating concept. Cost comparison primarily focuses on three major cost components in constructing unpaved roads. They are costs of labor, equipment and material.

Hours of equipment operation and labor were approximately estimated developing a construction process design, estimating the number hour to execute the design and multiplying the hourly costs with the number of hours and summing each cost element to provide a total. Motor-graders were assumed to work 50% longer than trucks to account for the relatively low speed travelling speed to mobilize from workshop to to the construction site and extra amount of time involved in grading the last spread of material.

CONSTRUCTION COST COMPARISON RESULTS

The calculated cost estimate was in dollars per mile.

Table 11 Construction Total Cost-Jackson County

Jackson County		
	Total Cost	Savings
West Section/1st Section/200.64 tons/mi	$ 4,025.56	
Mid Section/2nd Section/126.72 tons/mi	$ 3,364.62	16%
East Section/3rd Section/73.92 tons/mi	$ 2,108.76	48%

Table 12 Construction Total Cost-Beltrami County

Beltrami County		
	Total Cost	Savings
North Section/1st Section/166 ton/mi	$ 8,513.93	
Mid Section/2nd Section/83 ton/mi	$ 5,417.52	36%
South Section/3rd Section/50 ton/mi	$ 3,325.95	61%

Table 13 Construction Total Cost-Olmsted County

Olmsted Co. CR115	Total Cost
1st Section/Class 5/234.94 tons/mi	$ 23,236.60
2nd Section/2/3 Class 5 & 1/3 Lime/251.4 tons/mi	$ 22,528.43
3rd Section/1/2Class 5 & 1/2 Class 2/243 tons/mi	$ 25,050.04
4th Section/Class 2/270 tons/mi	$ 24,446.69

BENEFIT-COST ANALYSIS

Highway Department of Beltrami County actively maintains aggregate roads in the jurisdiction seven months out of a year, from late April to early November usually. By the end of September, 2014, the highway department had conducted eight maintenance activities on the South Section/3rd Section and five maintenance activities on the Middle Section/2nd Section and the north Section/3rd Section. The research team projected, based on the maintenance frequency observed, that there would probably be ten maintenance activities implemented on the South Section/3rd Section, eight on the Middle Section/2nd Section, and seven on the North Section/1st Section in 2014

In Beltrami County, roads are typically re-graveled every five years. Cost and maintenance information was solicited. Maintenance cost per mile each year for the South Section/3rd Section is $1,500, $1050 for the Middle Section/2nd Section, and $900 for the North Section/3rd Section. It is assumed that the cost for maintenance would be constant throughout the life cycle. Taking discount rate of 4% recommended by the Highway Department of Beltrami into account, the final result suggests that in a five-year cycle, a mile of aggregate road rejuvenated adopting method used in the Middle Section/2nd Section saved $2,400, a cost saving of 19%, and yet the performance is acceptably well. In the case of Beltrami, the cost savings increase as the re-gravel cycle is shortened.

Table 14 Benefit-cost Analysis-Beltrami County CR23

Beltrami County CR23			
	South Section	Middle Section	North Section
Construction Cost	$ 3,325.95	$ 5,417.52	$ 8,513.93
1st yr maintenance	1500	1050	900
2nd yr maintenance	1500	1050	900
3rd yr maintenance	1500	1050	900
4th yr maintenance	1500	1050	900
5th yr maintenance	1500	1050	900
Net present value	$ 10,270.79	$ 10,278.91	$ 12,680.83
Savings	19%	19%	

CHAPTER SUMMARY

Considerable economic saving was realized in the 3rd Section of both Jackson and Beltrami County, with nearly 50% cost savings for Jackson County and over 60% for Beltrami County in the upfront construction. The 2nd Section for the both counties provided cost-saving at the upfront as well. For Beltrami County, the saving was up to 36% and performance was acceptably well over the period of observation, according to the data analysis and site feedback.

Even though both the 2nd Section and the 3rd Section in Jackson County and Beltrami County demonstrated cost saving at the upfront, maintenance cost could balance out saving. Benefit-cost analysis was performed for Beltrami County. The result shows that in a five-year cycle, the Middle Section/2nd Section saved $2,400, a cost saving of 19%.

CHAPTER 6: RESEARCH FINDINGS

JACKSON COUNTY PERFORMANCE

The disappointing performance of the test sections in Jackson County can be likely attributed to the lacking of binding capacity of both the crusher dust and the in-situ material. Segregation resulted soon occurred after the arrival of dry weather. The East Section/3rd Section experienced a statistically significant amount of gravel loss according to a statistical analysis of cross section elevation results and likely resulted in road surface deterioration. Other issues cannot be ignored such as having inadequate amount of crusher dust to mix in with the in-situ material; this apparently led to uneven blending of the crusher dust and the in-situ material. Cost saving in construction was realized in comparison to the standard method of regraveling the road, but given the disappointing performance, the opportunity for cost savings is unlikely to be considered worthwhile,

BELTRAMI COUNTY PERFORMANCE

At the end of the observation period, the two experimental test sections in Beltrami County were performing better than those in Jackson County, apparently because the resulting aggregate on the surface after blending possesses some binding capacity. Although the two experimental sections were not as compacted as the control section which was surfaced with MnDOT Class 1 aggregate, they did hold up and provided a driving surface that met expectations during the observation period.

Between the two test sections, the Middle Section/2nd Section appeared to outperform the south section/3rd section in all dimensions. As the maintenance supervisor reflected in the notes and the collected data suggest, the Middle Section/2nd Section performed well compared to the North

Section/1st Section, which was the control section. The biggest concern over the South Section/3rd Section was the corrugation formed throughout the section.

A benefit-cost analysis revealed that the Middle Sections/2nd Section generate a cost saving up to 19%. From the performance point of view, the Middle Section/2nd Section provided acceptable surface for the road users while the South Section/3rd Section failed to.

OLMSTED COUNTY PERFORMANCE

The four sections provided excellent road surfaces for the road users. Remarks from maintenance supervisor and collected data suggested comparable performance among all four sections. However, due to the non-binding characteristic of limestone used to surface in Olmsted County, road surfacing material loss appeared to be higher. The two control sections that were constructed with Class 2 and Class 5 aggregate experienced cross sectional changes and excessive loose aggregate, respectively. The 2nd experimental sections generated the highest amounts of loose aggregate. The 3rd section was favorable as the trial results indicates.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

The alternative unpaved road rejuvenation method has an advantage in up-front construction cost if desired material is accessible in the local area. The four experimental sections have proved it to be valid. However, success of the alternative rejuvenation method is dependent on the accessibility of the desired material. Plasticity is desirable for some type of aggregate that has high relative mineral hardness such as granite. Clay and silt contained crusher dust increases the binding capacity of the resulting aggregate after mixing in and thus the resulting surfacing material provides better surface in case that the existing top size aggregate is derived from hard rock such as granite.

Ensuring the even distribution of the crusher dust is vitally important. Crusher dust stockpile in humid environment tends to form crust. Stockpile blending is necessary to deform the crust and reduce the moist preserved before it is loaded onto trucks.

Locally accessible resource is the fundamental premise of economic feasibility. The advantage in cost savings is promised by the reduction in trucking hours and material. Trucking cost makes up a large proportion of the total construction cost. Longer transportation distance would result in an increase in trucking cost which in return reduces the cost savings otherwise. It is advisable to perform an economic feasibility before adopting this method. Depending upon the location of the source of desired crusher dust, the cost savings is largely different even within the same jurisdiction.

REFERENCES

10e1, ASTM International D4318 (2010). "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils." ASTM International, ASTM International, West Conshokocken, PA,DOI: 10.1520/D4318, http://enterprise.astm.org/filtrexx40.cgi?+REDLINE_PAGES/D4318.htm (Date: 7/18/2014)

98, ASTM D1739 - (2010). "Standard Test Method for Collection and Measurement of Dustfall (Settleable Particulate Matter)." ASTM International, ASTM International, West Conshohocken, PA,10.1520/D1739-98R10, http://www.astm.org/Standards/D1739.htm (Date: 7/51/2014)

(TAMC), Michigan Transportation Asset Management Council (2009). "Policy for Collection of Roadway Condition Data on Federal-Aid Eligible Roads and Streets."

Administration, Federal Highway (2004). "Transportation Applications of Recycled Concrete Aggregate."Federal Highway Administration.

Africa, CSRA South (1989). "Guidelines for Road Construction Materials."

Army, Department of the (1995). *Unsurfaced Road Maintenance Management*, Departments of the Army, Navy, and Air Force.

Bennett, C. R., and Wang, H. (2003). "HARMONISING AUTOMATED RUT DEPTH MEASUREMENTS." *TRANSFUND NEW ZEALAND RESEARCH REPORT*(242), 65 p.

Bloser, Steven (2007). "Commonly Used Aggregate Materials and Placement Methods: Comparative Analysis for a Wearing Course on Low-Volume Roads in Pennsylvania." *Transportation Research Record: Journal of the Transportation Research Board*, 1989(-1), 178-185.

Brown, M., Mercier, S., and Provencher, Y. "Road maintenance with Opti-Grade: maintaining road networks to achieve the best value." 282-286 (Vol 281).

Bushman, William, Freeman, Thomas, and Hoppe, Edward (2005). "Stabilization Techniques for Unpaved Roads." *Transportation Research Record: Journal of the Transportation Research Board*, 1936(-1), 28-33.

D6951/6951M, ASTM Standard (2009). "Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications." ASTM International, ASTM International, West Conshokocken, PA,DOI: 10.1520/D6951_D6951M-

09, http://enterprise.astm.org/filtrexx40.cgi?+REDLINE_PAGES/D6951D6951M.htm (Date: 5/11/2014)

Division, Iowa Department of Transportation Highway (2012). "Standard specifications for highway and bridge construction." 1270.

Division, Project Development (1997). "Stressing Our Future." <http://www.iowadot.gov/agequip.pdf>. (Date: 9/25/2014)

E2583-07, ASTM International (2011). "Standard Test Method for Measuring Deflections with a Light Weight Deflectometer (LWD)." ASTM International, ASTM International, West Conshokocken, PA,DOI: 10.1520/E2583-07R11, http://enterprise.astm.org/filtrexx40.cgi?+REDLINE_PAGES/E2583.htm (Date: 7/1/2013)

Eaton, Robert A., Gerard, Sidney, and Dattilo, Ronald S. (1987). "A Rating System for Unsurfaced Roads to be Used in Maintenance Management." *2nd North American Pavement Management Conference (1987)*, Transportation Research Board, Washington, D.C.

Eatonl, R. A., Gerard, S., and Cate, D. W. (1987). "RATING UNSURFACED ROADS. A FIELD MANUAL FOR MEASURING MAINTENANCE PROBLEMS." 33 p.

George Huntington, and Khaled Ksaibati (2010). "Gravel Roads Management."Wyoming Technology Transfer Center.

Gesford, Alan L., and Anderson, John A. (2006). "Environmentally Sensitive Maintenance for Dirt and Gravel Roads." 332p.

Giummarra, G., Australian Road Research (2009). "Unsealed roads manual: guidelines to good practice."ARRB Group Limited, 500 Burwood Highway, Vermont South, Victoria, Australia, 3133.

Goodspeed, Charles H., Schmeckpeper, Edwin R., and Lemieux, Richard L. "Road Surface Management System." *Proc., 3rd International Conference on Managing Pavements*.

Huntington, George, and Ksaibati, Khaled "Gravel Roads Asset Management." Transportation Research Board, pp 214-228.

Inc., Asphalt Zipper (2013). "GRAVEL ROADS MAINTENANCE -- Texas County Rebuilds Their Gravel Roads for Less Now."

Irwin, L. H., Taylor, D. J., and Aneshansley, D. J. (1986). "Device to measure road dustiness on aggregate surfaced roads." 101p.

Jahren, C. T. (2001). "Best Practices For Maintaining And Upgrading Aggregate Roads In Australia And New Zealand." 75 p.

Johnson, Eddie N., and Olson, Roger C. (2001). "Best Practices for Dust Control on Aggregate Roads." *Transportation Research Record: Journal of the Transportation Research Board*.

Jones, D, and Paige-Green, P (2000). "DRAFT TMH12 Pavement Management Systems: Standard Visual Assessment Manual for Unsealed Roads Version 1. Contract Report CR-2000/66."Pretoria, South Africa.

Jones, Hans, and Forslof, Lars (2014). "Roadroid Continuous Road Condition Monitoring with Smart Phone." *IRF Regional Conference*.

LTAP, Utah (2011). "Utah LTAP Center's Transportation Asset Management System." Utah State University.

Mitra, Subhro, Tolliver, Denver, and Dybing, Alan (2012). "Analyzing Investments Needed to Support Oil and Gas Production and Distribution." *Transportation Research Record: Journal of the Transportation Research Board*(2307), pp 1-8.

No.T27, AASHTO (2012). "Sieve Analysis of Fine and Coarse Aggregates." American Association of State Highway and Transportation, 444 North Capitol St. N.W., Suite 225, Washington, DC 20001, http://www.dot.nd.gov/manuals/materials/testingmanual/t27.pdf (Date: 10/11/2014)

Oman, Matthew, Deusen, Dave Van, and Olson, Roger (2001). "Scoping Study: Impact of Agricultural Equipment on Minnesota's Low Volume Roads."Minnesota, 42.

Romadas (2011). "Romdas Laser Rut Measurement System." <http://www.romdas.com/romdascd/Brouchure/specs/11-12-16-ROMDAS-LRMS.pdf>.(Date: 7/1/2014)

Sanders, T., Addo, J., Ariniello, A., and Heiden, W. (1997). "Relative Effectiveness of Road Dust Suppressants." *Journal of Transportation Engineering*, 123(5), 393-397.

Sanders, T. G., and Addo, J. Q. (2000). "EXPERIMENTAL ROAD DUST MEASUREMENT DEVICE." *Journal of Transportation Engineering*, 126(6), p. 530-535.

Skoreth, Ted Eggebraaten and Ken (2012). "SDDOT-SDLTAP Gravel Experiment Project."

Skorseth, Ken, and Selim, Ali (2000). *Gravel roads: maintenance and design manual*, U.S. Dept. of Transportation, Federal Highway Administration.

Studies, Center for Dirt & Gravel Roads (2005). "Crown & Cross-Slope."

Studies, Center for Dirt & Gravel Roads (2005). "Information Bulletin:Rotating Carbide-Tipped Grader Blades." <http://www.dirtandgravel.psu.edu/Resources/Documents/carbide_blade.pdf>. (Date: 7/1/2013)

Studies, Center for Dirt & Gravel Roads (2009). "Information Bulletin: Driving Surface Aggregate."

Surdahl, Roger W., Woll, J. Heather, and Marquez, Rick (2005). "Road Stablizer Product Performance: Buenos Aires National Wildlife Refuge."

Taylor, Charles (2010). "Counties turn some paved roads back to gravel." <http://www.naco.org/newsroom/countynews/Current%20Issue/12-13-10/Pages/Countiesturnsomepavedroadsbacktogravel.aspx>. (Date: 7/3/2013)

Transportation, Minnesota Department of (2005). "Mn/DOT Standard Specifications for Construction."

USDOT (2010). "Table 1-4: Public Road and Street Mileage in the United States by Type of Surface(a) (Thousands of miles)." <http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_04.html>. (Date: 5/3/2013)

Walker, Donald, Enitne, Lynn, and Kummer, Susan (2001). "Gravel-PASER Manual, Pavement Surface Evaluation and Rating."Transportation Information Center-University of Wisconsin-Madison, 20.

Walker, Donald, Enitne, Lynn, and Kummer, Susan (2002). "Pavement Surface Evaluation and Rating (PASER) Gravel Roads Manual."University of Wisconsin-Madison.

Woll, J. Heather, Surdahl, Roger W., Everett, Randy, and Andersen, Ron (2008). "Road Stablizer Product Performance: Seedskadee National Wildlife Refuge." 106.

Wood, Thomas J., Johnson, Eddie N., and Cole, Melissa K. (2014). "Research Using Waste Shingles for Stabilization or Dust Control for Gravel Roads and Shoulders." 48p.

Zhang, Chunsun (2007). "Monitoring the Condition of Unpaved Roads with Remote Sensing and other Technology." *Transportation Research Record: Journal of the Transportation Research Board*.

APPENDIX A: GRADATION RAW DATA

Beltrami County/Top Material			
Sieve Size	Percentage Passing		
	CR23		Average
	#1	#2	
1.5"	100.0%	100.0%	100.0%
1"	100.0%	100.0%	100.0%
3/4"	100.0%	100.0%	100.0%
3/8"	95.1%	95.2%	95.1%
#4	84.7%	83.2%	83.9%
#8	N/A	N/A	N/A
#10	67.8%	62.3%	65.0%
#30	N/A	N/A	N/A
#40	28.1%	23.9%	26.0%
#100	N/A	N/A	N/A
#200	2.3%	2.1%	2.2%
<#200	0.0%	0.0%	0.0%

Beltrami County/Bottom Material			
Sieve Size	Percentage Passing		
	CR23		Average
	#1	#2	
1.5"	100.0%	100.0%	100.0%
1"	100.0%	100.0%	100.0%
3/4"	100.0%	100.0%	100.0%
3/8"	95.8%	96.8%	96.3%
#4	89.1%	89.1%	89.1%
#8	N/A	N/A	N/A
#10	78.2%	79.4%	78.8%
#30	N/A	N/A	N/A
#40	46.5%	47.9%	47.2%
#100	N/A	N/A	N/A
#200	7.3%	7.1%	7.2%
<#200	0.0%	0.0%	0.0%

Jackson County/Top Material			
Sieve Size	Percentage Passing		
	CR76		Average
	#1	#2	
1.5"	100.0%	100.0%	100.0%
1"	100.0%	100.0%	100.0%
3/4"	99.3%	98.6%	99.0%
3/8"	89.9%	86.7%	88.3%
#4	79.0%	76.1%	77.6%
#8	N/A	N/A	N/A
#10	59.0%	58.4%	58.7%
#30	N/A	N/A	N/A
#40	20.6%	20.1%	20.4%
#100	N/A	N/A	N/A
#200	4.2%	4.2%	4.2%
<#200	0.0%	0.0%	0.0%

Jackson County/Bottom Material			
Sieve Size	Percentage Passing		
	CR76		Average
	#1	#2	
1.5"	100.0%	100.0%	100.0%
1"	100.0%	100.0%	100.0%
3/4"	98.9%	98.4%	98.6%
3/8"	94.0%	91.4%	92.7%
#4	87.0%	82.7%	84.9%
#8	N/A	N/A	N/A
#10	75.6%	71.1%	73.4%
#30	N/A	N/A	N/A
#40	41.2%	38.5%	39.9%
#100	N/A	N/A	N/A
#200	12.7%	11.7%	12.2%
<#200	0.0%	0.0%	0.0%

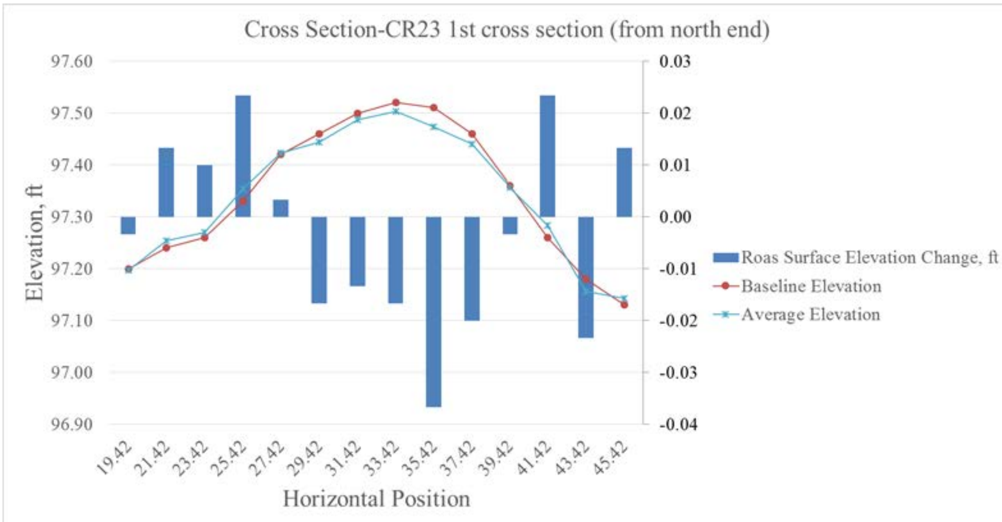
Olmsted County/Top Material			
Sieve Size	Percentage Passing		
	North CR115		Average
	#1	#2	
1.5"	100.0%	100.0%	100.0%
1"	100.0%	100.0%	100.0%
3/4"	100.0%	100.0%	100.0%
3/8"	75.4%	81.3%	78.4%
#4	39.9%	54.3%	47.1%
#8	N/A	N/A	N/A
#10	20.9%	35.3%	28.1%
#30	N/A	N/A	N/A
#40	11.7%	21.8%	16.8%
#100	N/A	N/A	N/A
#200	6.6%	12.2%	9.4%
<#200	0.0%	0.0%	0.0%

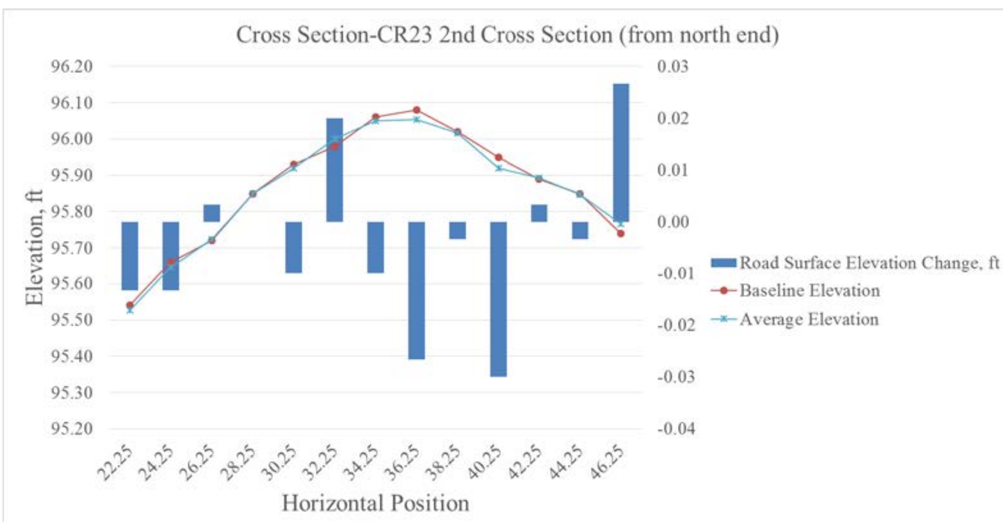
Olmsted County/Bottom Material			
Sieve Size	Percentage Passing		
	North CR115		Average
	#1	#2	
1.5"	100.0%	100.0%	100.0%
1"	100.0%	100.0%	100.0%
3/4"	100.0%	100.0%	100.0%
3/8"	89.0%	89.2%	89.1%
#4	66.5%	67.9%	67.2%
#8	N/A	N/A	N/A
#10	46.6%	48.5%	47.5%
#30	N/A	N/A	N/A
#40	28.8%	33.1%	30.9%
#100	N/A	N/A	N/A
#200	10.9%	19.8%	15.4%
<#200	0.0%	0.0%	0.0%

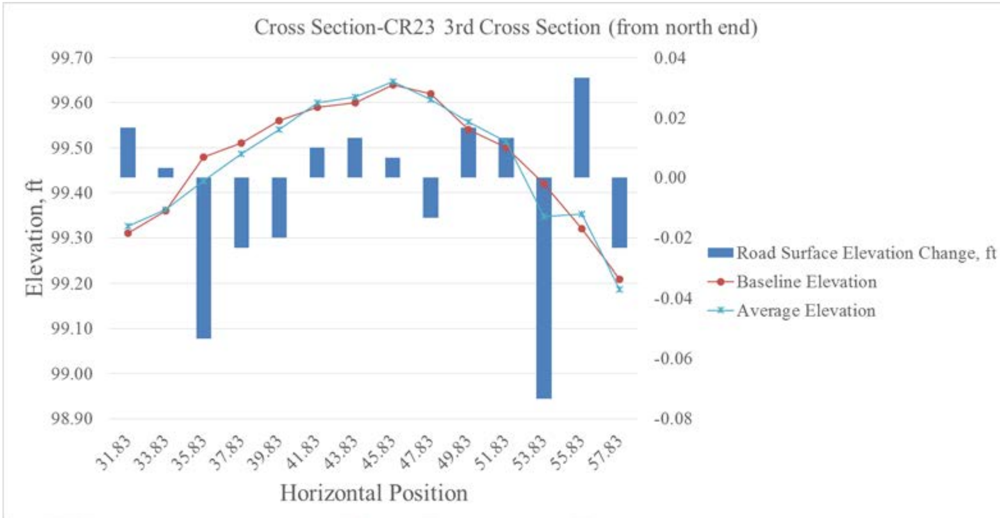
Olmsted County/Top Material			
Sieve Size	Percentage Passing		
	South CR115		Average
	#1	#2	
1.5"	100.0%	100.0%	100.0%
1"	100.0%	100.0%	100.0%
3/4"	100.0%	100.0%	100.0%
3/8"	81.2%	84.2%	82.7%
#4	55.8%	51.9%	53.8%
#8	N/A	N/A	N/A
#10	36.1%	30.5%	33.3%
#30	N/A	N/A	N/A
#40	22.1%	18.0%	20.0%
#100	N/A	N/A	N/A
#200	13.4%	10.6%	12.0%
<#200	0.0%	0.0%	0.0%

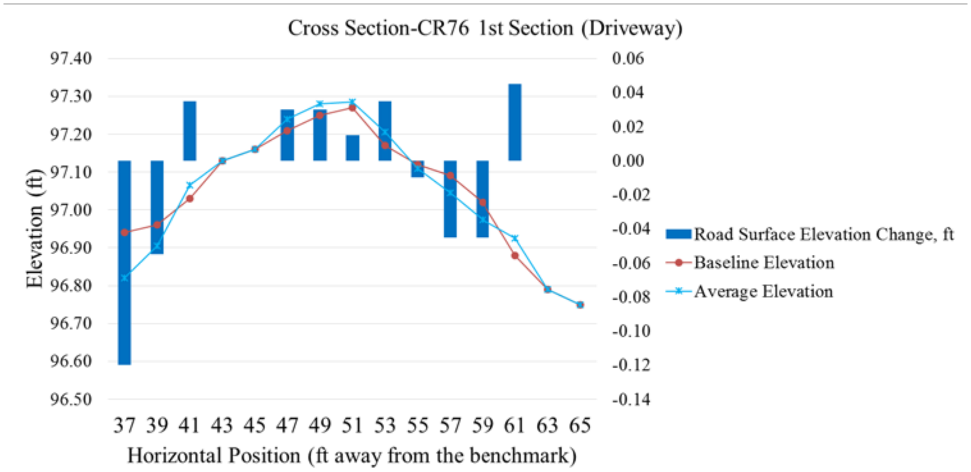
Olmsted County/Bottom Material			
Sieve Size	Percentage Passing		
	South CR115		Average
	#1	#2	
1.5"	100.0%	100.0%	100.0%
1"	100.0%	100.0%	100.0%
3/4"	100.0%	100.0%	100.0%
3/8"	91.2%	91.3%	91.2%
#4	73.3%	71.6%	72.4%
#8	N/A	N/A	N/A
#10	54.2%	52.4%	53.3%
#30	N/A	N/A	N/A
#40	35.1%	34.3%	34.7%
#100	N/A	N/A	N/A
#200	21.5%	21.1%	21.3%
<#200	0.0%	0.0%	0.0%

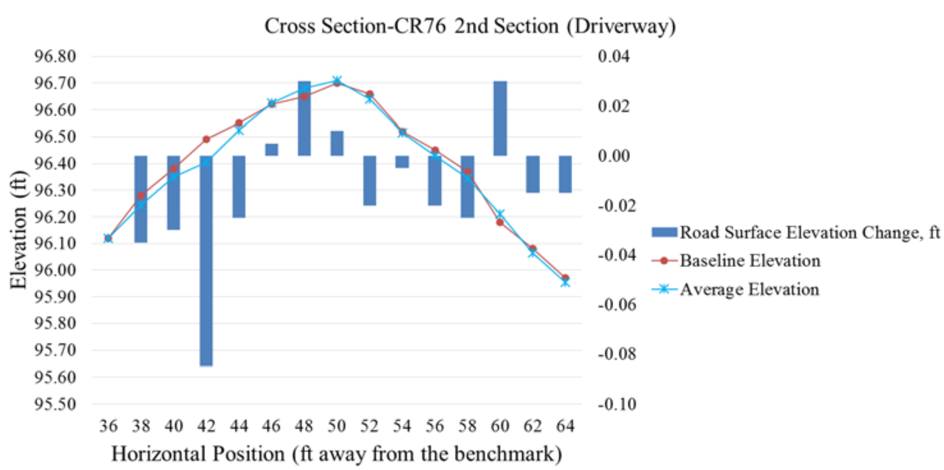
APPENDIX B: CROSS SECTION PROFILE

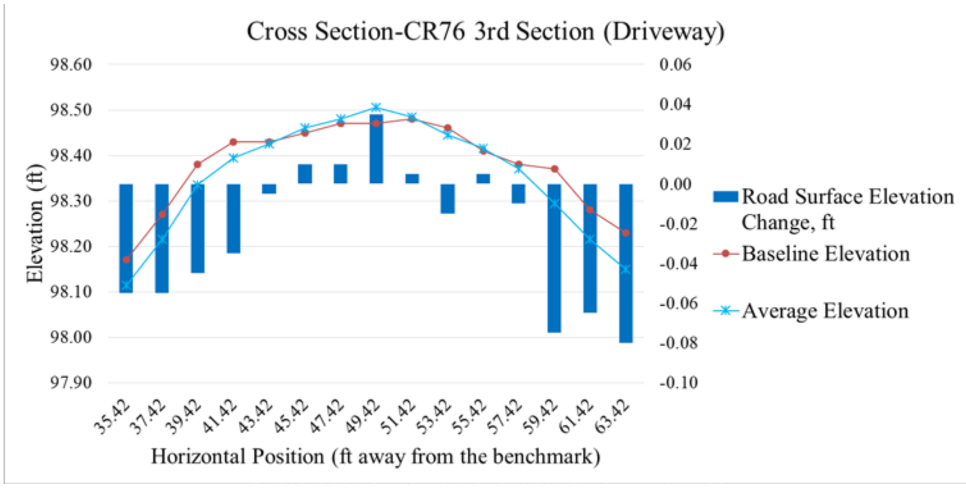




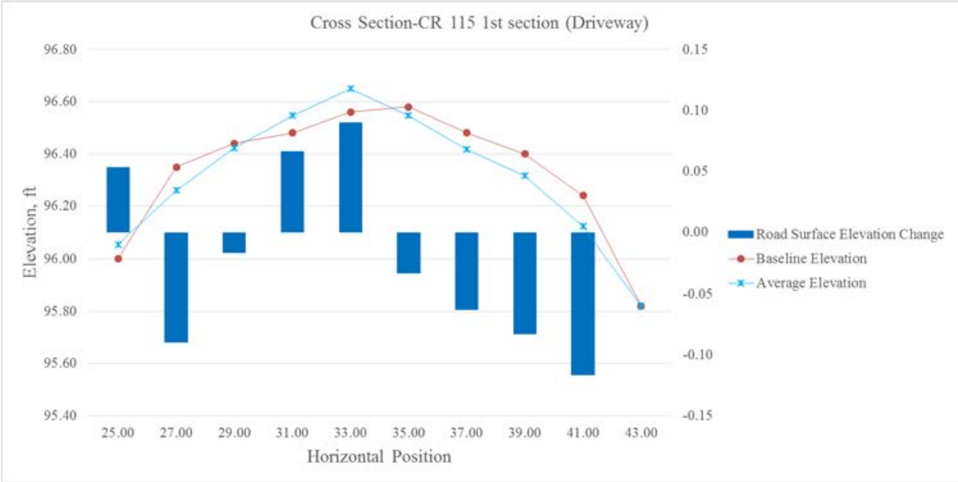

Cross Section-CR23 3rd Cross Section (from north end)
Elevation, ft
Horizontal Position
Road Surface Elevation Change, ft
Baseline Elevation
Average Elevation


Cross Section-CR76 1st Section (Driveway)
Elevation (ft)
Horizontal Position (ft away from the benchmark)
Road Surface Elevation Change, ft
Baseline Elevation
Average Elevation

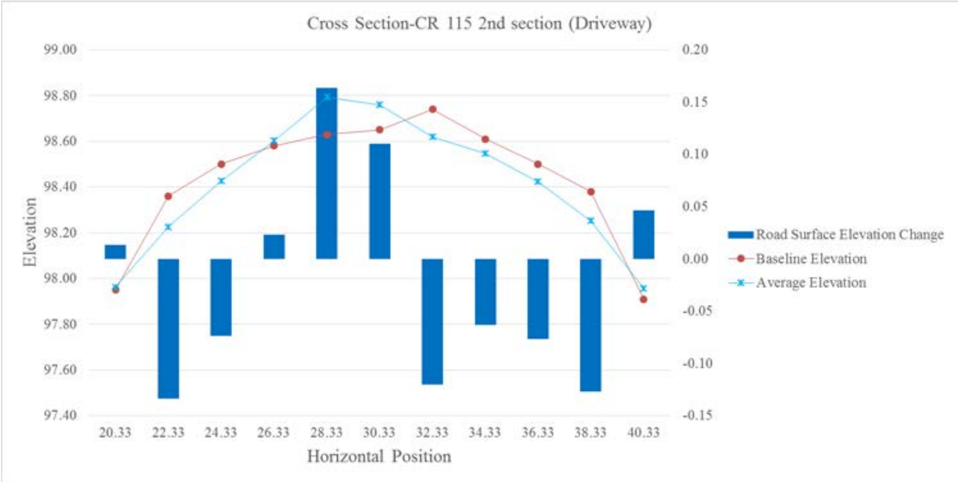

Cross Section-CR76 2nd Section (Drirverway)
Elevation (ft)
Horizontal Position (ft away from the benchmark)
Road Surface Elevation Change, ft
Baseline Elevation
Average Elevation



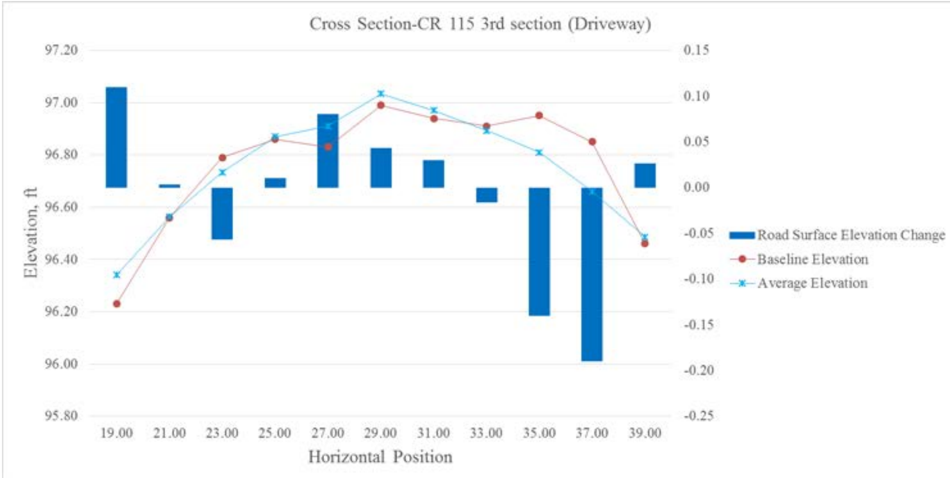
Cross Section-CR76 3rd Section (Driveway)
Elevation (ft)
Horizontal Position (ft away from the benchmark)
Road Surface Elevation Change, ft
Baseline Elevation
Average Elevation



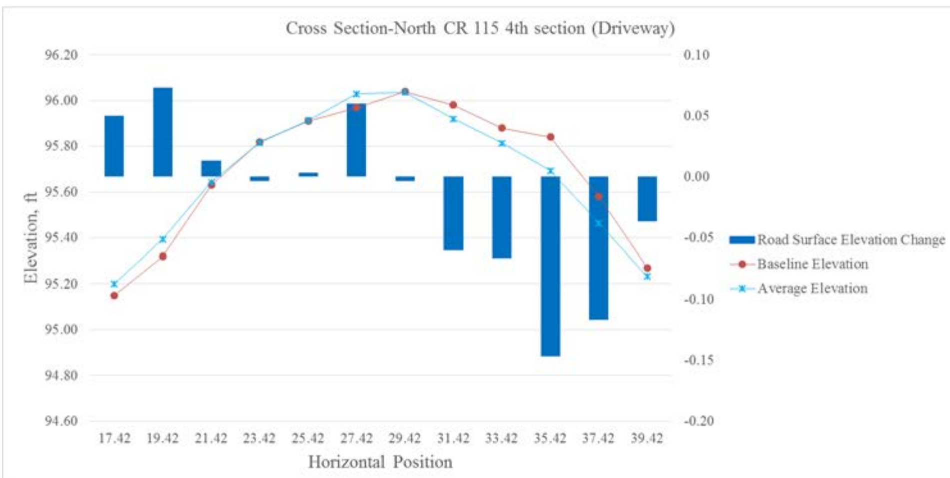
Cross Section-CR 115 1st section (Driveway)
Elevation, ft
Horizontal Position
Road Surface Elevation Change
Baseline Elevation
Average Elevation



Cross Section-CR 115 2nd section (Driveway)
Elevation
Horizontal Position
Road Surface Elevation Change
Baseline Elevation
Average Elevation



Cross Section-CR 115 3rd section (Driveway)
Elevation, ft
Horizontal Position
97.20
97.00
96.80
96.60
96.40
96.20
96.00
95.80
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
19.00
21.00
23.00
25.00
27.00
29.00
31.00
33.00
35.00
37.00
39.00
Road Surface Elevation Change
Baseline Elevation
Average Elevation



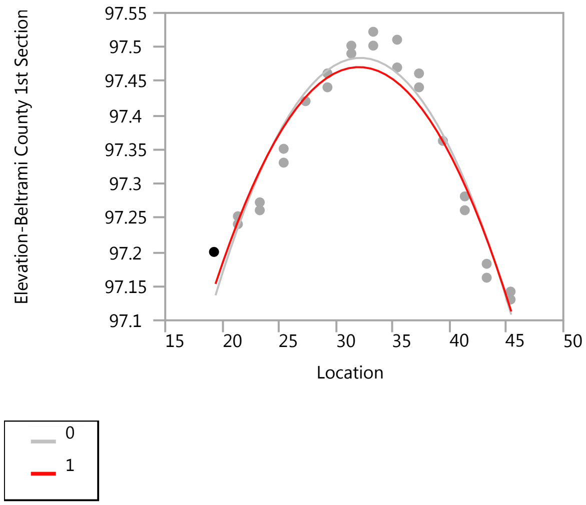
Cross Section-North CR 115 4th section (Driveway)
Elevation, ft
Horizontal Position
96.20
96.00
95.80
95.60
95.40
95.20
95.00
94.80
94.60
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
17.42
19.42
21.42
23.42
25.42
27.42
29.42
31.42
33.42
35.42
37.42
39.42
Road Surface Elevation Change
Baseline Elevation
Average Elevation

APPENDIX C: STATISTICAL ANALYSIS RESULTS

COMPARISON OF MULTIPLE CURVES

Response Elevation-Beltrami County 1st Section

Regression Plot



Summary of Fit

RSquare	**0.924477**
RSquare Adj	0.907313
Root Mean Square Error	0.038642
Mean of Response	97.34286
Observations (or Sum Wgts)	28

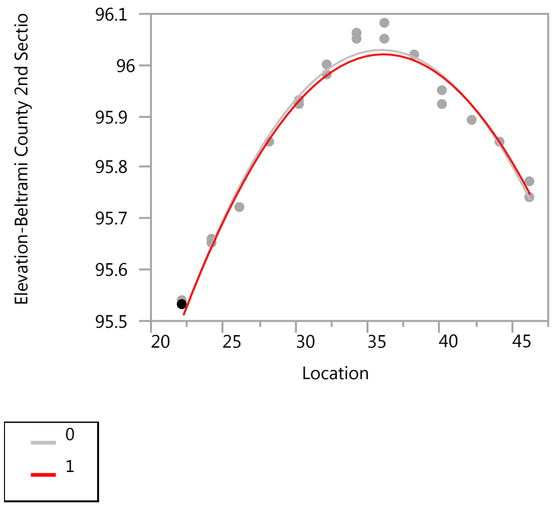
Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	97.519333	0.044348	2199.0	**<.0001***

Term	Estimate	Std Error	t Ratio	Prob>|t|
Time[1-0]	-0.013661	0.022003	-0.62	0.5411
Location	-0.001088	0.001281	-0.85	0.4049
(Location-32.42)*(Location-32.42)	-0.002139	0.000179	-11.95	**<.0001***
(Location-32.42)*(Location-32.42)*Time[1-0]	0.0001442	0.000253	0.57	0.5747
(Location-32.42)*Time[1-0]	-0.000462	0.001812	-0.25	0.8013

Response Elevation-Beltrami County 2nd Section

Regression Plot



Summary of Fit

RSquare	**0.9689**
RSquare Adj	0.961125
Root Mean Square Error	0.031166
Mean of Response	95.865
Observations (or Sum Wgts)	26

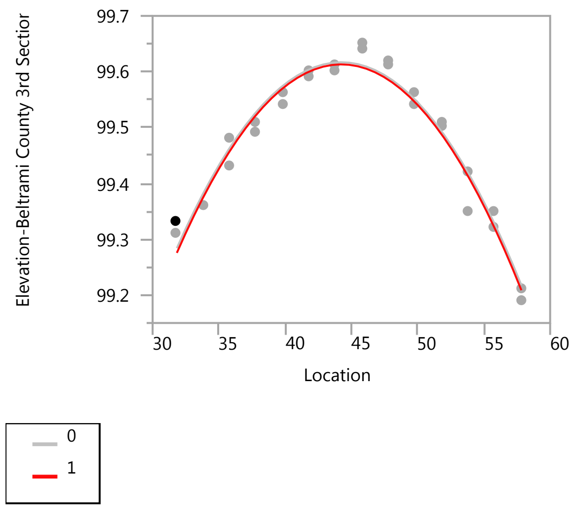
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	95.70082	0.041653	2297.6	**<.0001***

Term	Estimate	Std Error	t Ratio	Prob>|t|
Time[1-0]	-0.00979	0.018429	-0.53	0.6011
Location	0.0093681	0.001155	8.11	**<.0001***
(Location-34.25)*(Location-34.25)	-0.002763	0.000174	-15.87	**<.0001***
(Location-34.25)*(Location-34.25)*Time[1-0]	0.0001061	0.000246	0.43	0.6711
(Location-34.25)*Time[1-0]	0.000467	0.001634	0.29	0.7779

Response Elevation-Beltrami County 3rd Section

Regression Plot



Summary of Fit

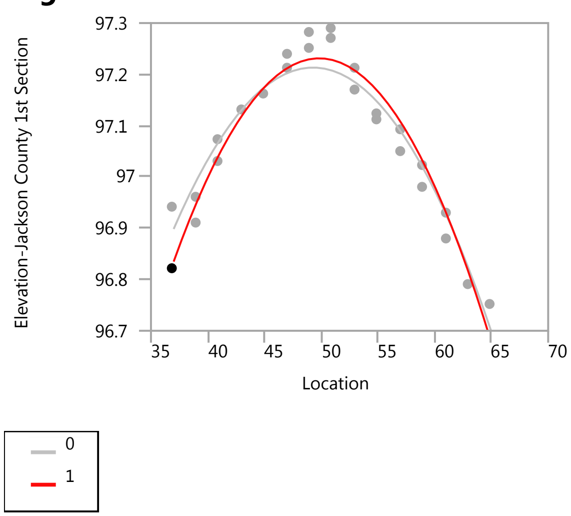
RSquare	**0.960138**
RSquare Adj	0.951079
Root Mean Square Error	0.029256
Mean of Response	99.47286
Observations (or Sum Wgts)	28

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	99.73052	0.045044	2214.1	**<.0001***
Time[1-0]	-0.003817	0.016658	-0.23	0.8209
Location	-0.002549	0.00097	-2.63	**0.0153***
(Location-44.83)*(Location-44.83)	-0.002162	0.000136	-15.95	**<.0001***
(Location-44.83)*(Location-44.83)*Time[1-0]	-2.919e-5	0.000192	-0.15	0.8803
(Location-44.83)*Time[1-0]	-0.000022	0.001372	-0.02	0.9874

Response Elevation-Jackson County 1st Section

Regression Plot



Summary of Fit

RSquare	**0.948536**
RSquare Adj	0.937814
Root Mean Square Error	0.04156
Mean of Response	97.04967

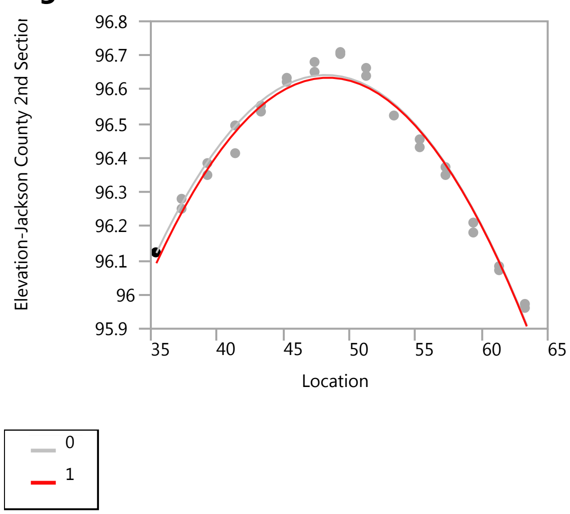
Observations (or Sum Wgts) 30

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	97.572291	0.065363	1492.8	**<.0001***
Time[1-0]	0.0208597	0.022849	0.91	0.3704
Location	-0.007161	0.001242	-5.77	**<.0001***
(Location-51)*(Location-51)	-0.002086	0.000162	-12.90	**<.0001***
(Location-51)*(Location-51)*Time[1-0]	-0.000324	0.000229	-1.42	0.1695
(Location-51)*Time[1-0]	0.0015	0.001756	0.85	0.4015

Response Elevation-Jackson County 2nd Section

Regression Plot



Summary of Fit

RSquare	**0.972057**
RSquare Adj	0.966236

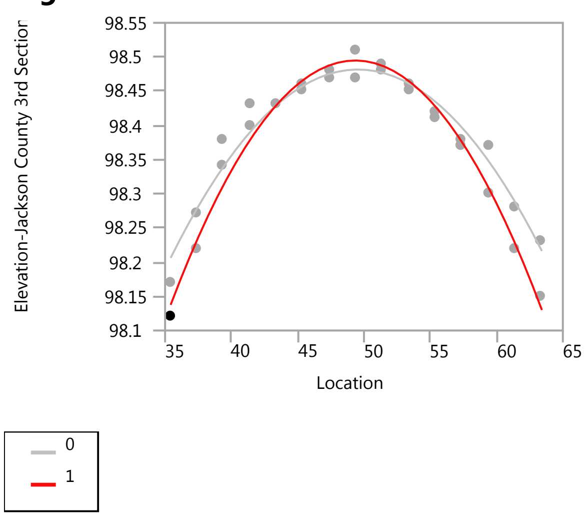
Root Mean Square Error	0.041889
Mean of Response	96.396
Observations (or Sum Wgts)	30

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	97.010732	0.063966	1516.6	<.0001*
Time[1-0]	-0.006805	0.02303	-0.30	0.7702
Location	-0.007536	0.001252	-6.02	<.0001*
(Location-49.42)*(Location-49.42)	-0.003174	0.000163	-19.47	<.0001*
(Location-49.42)*Time[1-0]	0.0009286	0.00177	0.52	0.6047
(Location-49.42)*(Location-49.42)*Time[1-0]	-5.171e-5	0.000231	-0.22	0.8244

Response Elevation-Jackson County 3rd Section

Regression Plot



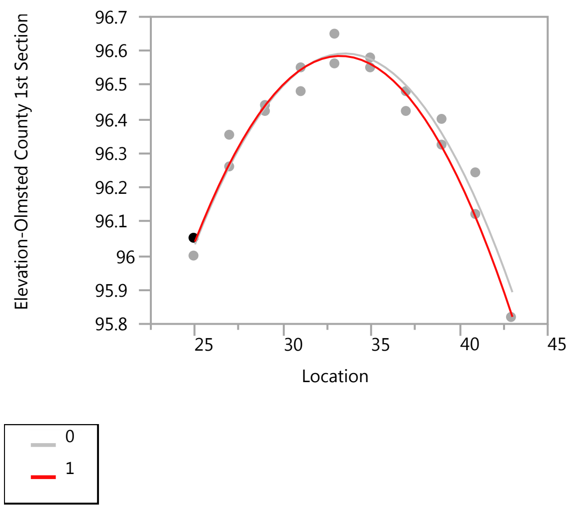
Summary of Fit

RSquare	**0.974812**
RSquare Adj	0.969564
Root Mean Square Error	0.019504
Mean of Response	98.368
Observations (or Sum Wgts)	30

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	98.464033	0.029784	3306.0	**<.0001***
Time[1-0]	0.0132217	0.010723	1.23	0.2295
Location	0.0003571	0.000583	0.61	0.5458
(Location-49.42)*(Location-49.42)	-0.00138	0.000076	-18.17	**<.0001***
(Location-49.42)*(Location-49.42)*Time[1-0]	-0.000463	0.000107	-4.31	**0.0002***
(Location-49.42)*Time[1-0]	-0.000625	0.000824	-0.76	0.4557

Response Elevation-Olmsted County 1st Section
Regression Plot



Summary of Fit

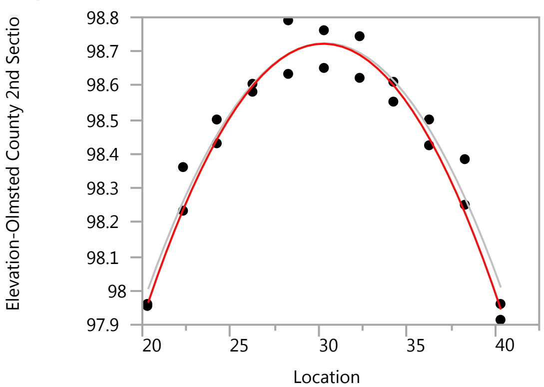
RSquare	**0.969061**
RSquare Adj	0.958011
Root Mean Square Error	0.050577
Mean of Response	96.3255
Observations (or Sum Wgts)	20

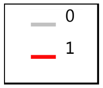
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	96.855413	0.097705	991.30	**<.0001***
Time[1-0]	-0.009938	0.034221	-0.29	0.7758
Location	-0.007788	0.002784	-2.80	**0.0143***
(Location-34)*(Location-34)	-0.007746	0.00055	-14.08	**<.0001***
(Location-34)*(Location-34)*Time[1-0]	-0.000275	0.000778	-0.35	0.7294
(Location-34)*Time[1-0]	-0.004455	0.003937	-1.13	0.2769

Response Elevation-Olmsted County 2nd Section

Regression Plot





Summary of Fit

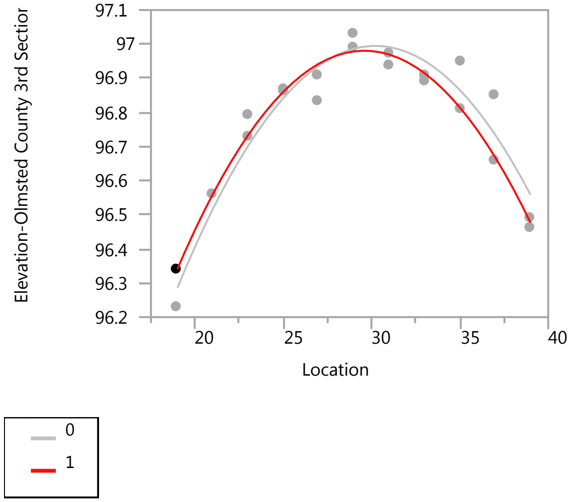
RSquare	**0.956368**
RSquare Adj	0.942733
Root Mean Square Error	0.065833
Mean of Response	98.42636
Observations (or Sum Wgts)	22

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	98.717442	0.099801	989.14	**<.0001***
Time[1-0]	-0.001655	0.042406	-0.04	0.9694
Location	0.0002273	0.003138	0.07	0.9432
(Location-30.33)*(Location-30.33)	-0.007177	0.000562	-12.77	**<.0001***
(Location-30.33)*(Location-30.33)*Time[1-0]	-0.000504	0.000795	-0.63	0.5348
(Location-30.33)*Time[1-0]	-0.001227	0.004438	-0.28	0.7857

Response Elevation-Olmsted County 3rd Section

Regression Plot



Summary of Fit

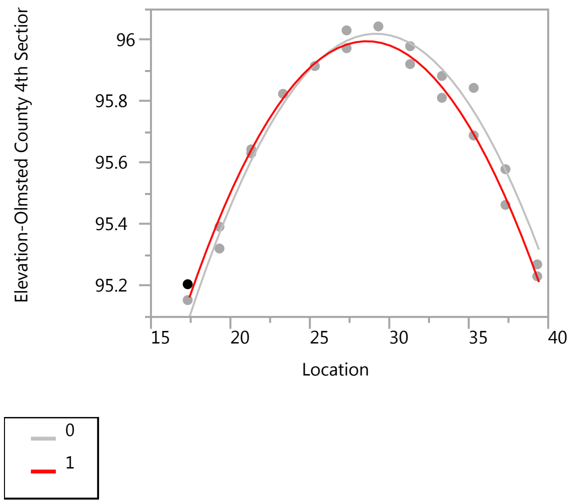
RSquare	**0.939231**
RSquare Adj	0.92024
Root Mean Square Error	0.063136
Mean of Response	96.75591
Observations (or Sum Wgts)	22

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	96.591329	0.091903	1051.0	**<.0001***
Time[1-0]	-0.008019	0.040669	-0.20	0.8462
Location	0.0136364	0.00301	4.53	**0.0003***
(Location-29)*(Location-29)	-0.005647	0.000539	-10.48	**<.0001***
(Location-29)*(Location-29)*Time[1-0]	-4.953e-5	0.000762	-0.06	0.9490
(Location-29)*Time[1-0]	-0.006864	0.004257	-1.61	0.1264

Response Elevation-Olmsted County 4th Section

Regression Plot



Summary of Fit

RSquare	**0.98567**
RSquare Adj	0.981689
Root Mean Square Error	0.039876
Mean of Response	95.68875
Observations (or Sum Wgts)	24

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	95.733886	0.050467	1896.9	**<.0001***
Time[1-0]	-0.020804	0.024564	-0.85	0.4082
Location	0.0099825	0.001667	5.99	**<.0001***
(Location-28.42)*(Location-28.42)	-0.00668	0.000273	-24.48	**<.0001***
(Location-28.42)*(Location-28.42)*Time[1-0]	-6.244e-7	0.000386	-0.00	0.9987
(Location-28.42)*Time[1-0]	-0.00771	0.002358	-3.27	**0.0043***

PAIRED T-TEST RESULT

t-Test: Paired Two Sample for Means-Jackson County Section #3 Crown

	Variable 1	*Variable 2*
Mean	98.448125	98.44375
Variance	0.001928125	0.001198214
Observations	8	8
Pearson Correlation	0.94985466	
Hypothesized Mean Difference	0	
df	7	
t Stat	0.800700628	
P(T<=t) one-tail	0.224811316	
t Critical one-tail	1.894578605	
P(T<=t) two-tail	**0.449622633**	
t Critical two-tail	2.364624252	

t-Test: Paired Two Sample for Means-Jackson County Section #3 8 ft Away from the Center

	Variable 1	*Variable 2*
Mean	98.24571429	98.30428571
Variance	0.010136905	0.008528571
Observations	7	7
Pearson Correlation	0.989969309	
Hypothesized Mean Difference	0	
df	6	
t Stat	-9.68624054	
P(T<=t) one-tail	3.47231E-05	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	**6.94463E-05**	
t Critical two-tail	2.446911851	

t-Test: Paired Two Sample for Means-Olmsted County Section #4 North Bound

	Variable 1	*Variable 2*
Mean	95.71904762	95.69142857
Variance	0.10434709	0.116380952
Observations	7	7
Pearson Correlation	0.996688199	
Hypothesized Mean Difference	0	
df	6	
t Stat	2.246330341	
P(T<=t) one-tail	0.032886064	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.065772127	
t Critical two-tail	2.446911851	

t-Test: Paired Two Sample for Means-Olmsted County Section #4 South Bound

	Variable 1	*Variable 2*
Mean	95.62466667	95.71
Variance	0.076675556	0.0823
Observations	5	5
Pearson Correlation	0.987877152	
Hypothesized Mean Difference	0	
df	4	
t Stat	-4.23966589	
P(T<=t) one-tail	0.006633547	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	**0.013267094**	
t Critical two-tail	2.776445105	

APPENDIX D: EXAMPLE OF UNPAVED ROAD CONDITION RATING SYSTEM (FOR BELTRAMI COUNTY)

South CR115 South End/Date

Rutting	9	8	7	6	5	4	3	2	1
	Very Good	Good		Fair		Poor		Very Poor	Failed
Discription	No or negligible ruts	Ruts <1" deep; ruts over <5% roadway		Ruts 1" to 3" deep; ruts over 5% to 15% of road way		Ruts 3" to 6" deep; Rut over 10% to 40% of roadway; Drivers tend to drive between the ruts not through them		Ruts 6" to 12" deep;	Ruts over 12" deep;

Washboarding	9	8	7	6	5	4	3	2	1
	Very Good	Good		Fair		Poor		Very Poor	Failed
Discription	No or negligible corrugations	Corrugations generally <1" deep; less than 10% of roadway with significant corrugations; little loss of vehicle control.		Corrugations generally 1"-2" deep;10%-25% of roadway with significant corrugations;some area safety is significantly compromised as vehicle lost control		Corrugations generally 2"-3" deep;over 25% of roadway with significant corrugations; Major safety issue as drivers are tempted to driver faster, skimming over the top of the corrugations.		Similar to "Poor" but deeper and more extensive corrugations	Similar to "Very Poor" but deeper and more extensive corrugations

Potholes	9	8	7	6	5	4	3	2	1
	Very Good	Good		Fair		Poor		Very Poor	Failed
Discription	No or negligible potholes	Some small potholes; most <1" deep and <1' in diameter		Up to 3" deep though most <2"; <2" diameter;		Many potholes; up to 4" deep and 3' in diameter		Up to 8" deep and >4' in diameter	Impassable

Loose Aggregate	9	8	7	6	5	4	3	2	1
	Very Good	Good		Fair		Poor		Very Poor	Failed
Discription	No or negligible loose aggregate; Negligible risk of chipped windshields	Loose aggregate in berms <1" deep; Loose aggregate usu. <3/4" thick.		Loose aggregate in berms <2" deep; Loose aggregate usu. <1.5" thick.		Loose aggregate in berms 2"- 4" deep;		Loose aggregate in berms >4" deep;	Sand dunes

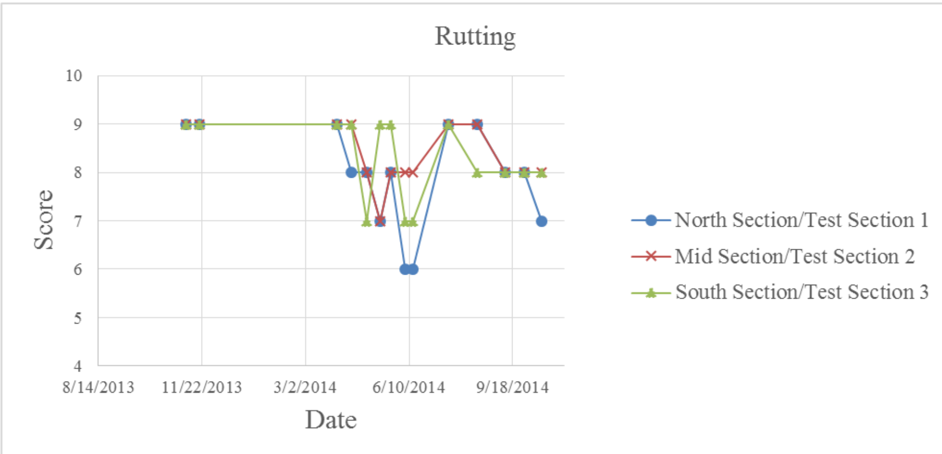
Dust	3	2	1	0	U
	None	Low	Medium	High	Not Rated
Discription	No visible dust	Minor dust emissions; No visibility obstruction	Significant dust emissions; Dust loss is major concern from a material	Heavy dust emission; Dust loss is major concern from a material loss standpoint but this	Due to the moisture in the top road surface material, dust was not assessed

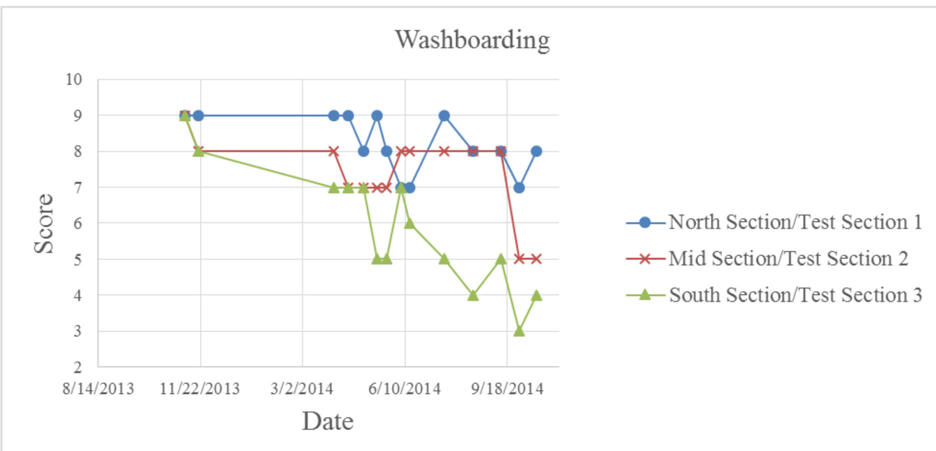
Crown	3	2	1
	Good	Fair	Poor
Discription	Cross slope >3%; Good rooftop shape	Cross slope 1% to 3%;	Cross slope <1%

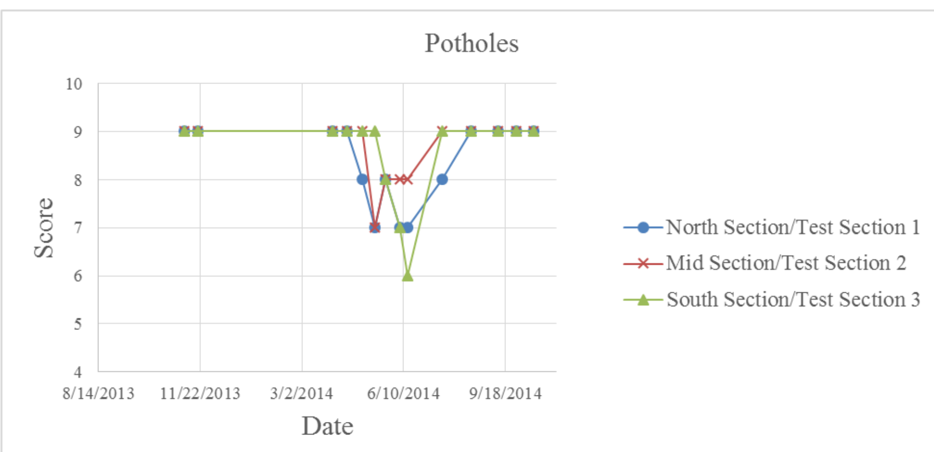
Roadside Drainage	3	2	1
	Good	Fair	Poor
Discription	Roadway above surrounding terrain; Good foreslopes; Ditches and culverts	Roadway near the grade of surrounding terrain; Good foreslopes; Marginal foreslopes,	Roadway at or below the grade of the surrounding terrain; Few or no ditches: Runoff

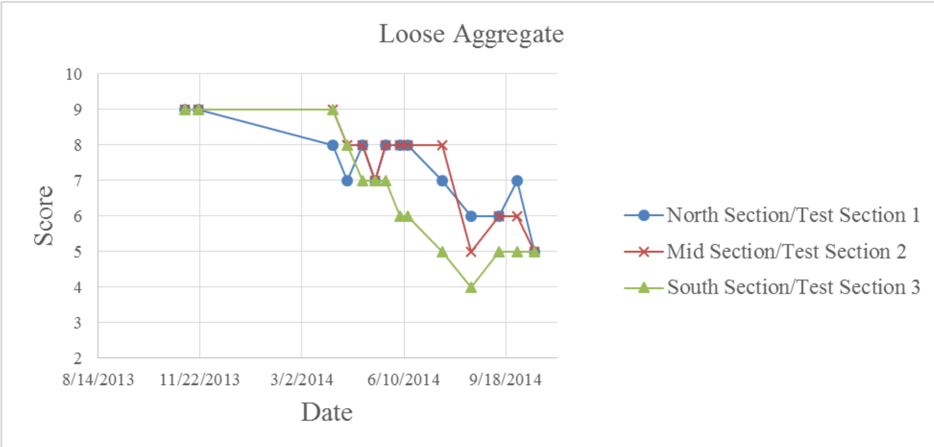
APPENDIX E: RATING SCORE GRAPHS

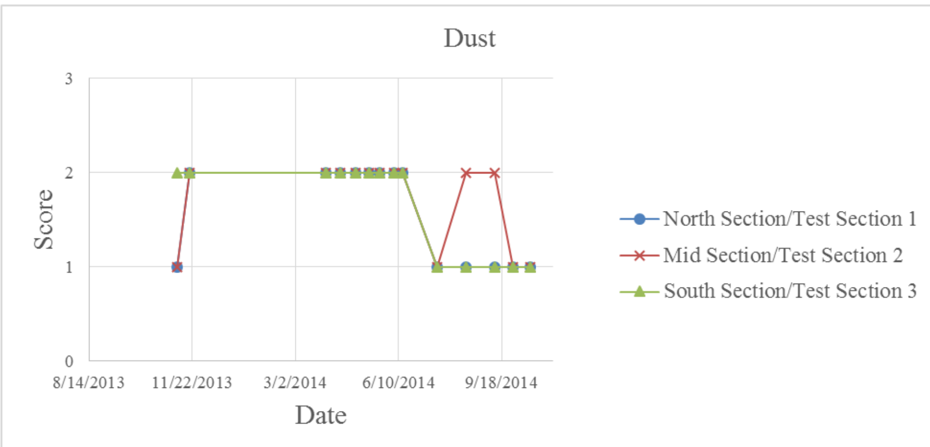
BELTRAMI COUNTY

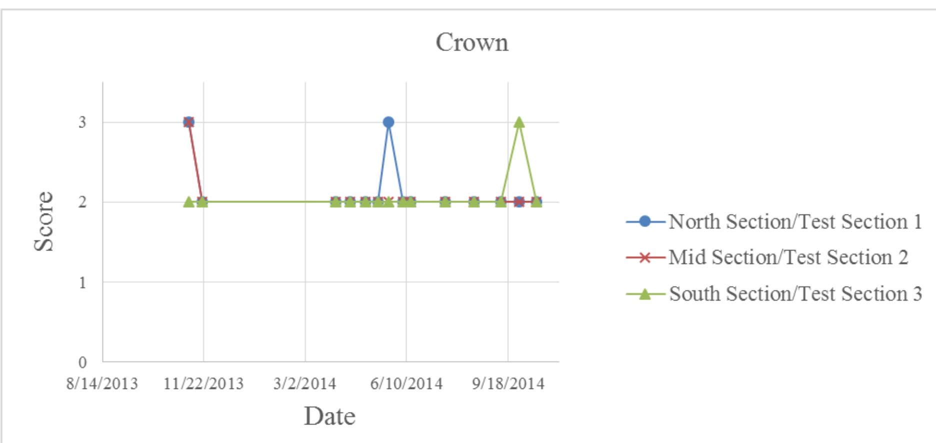


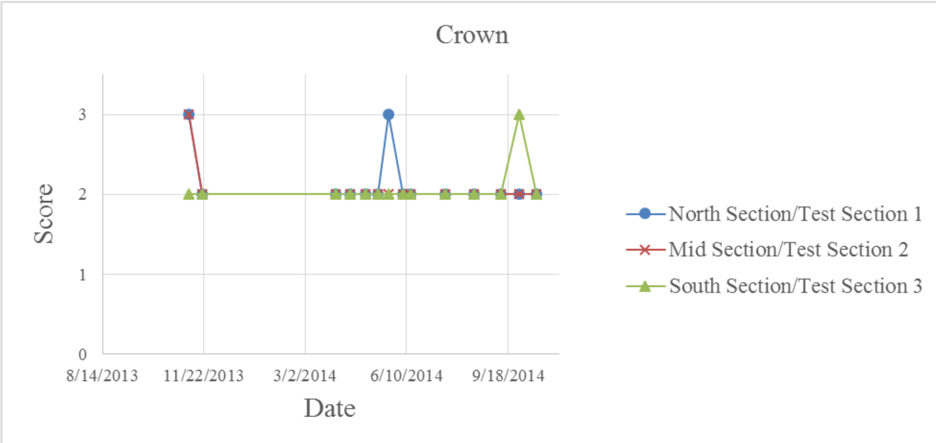




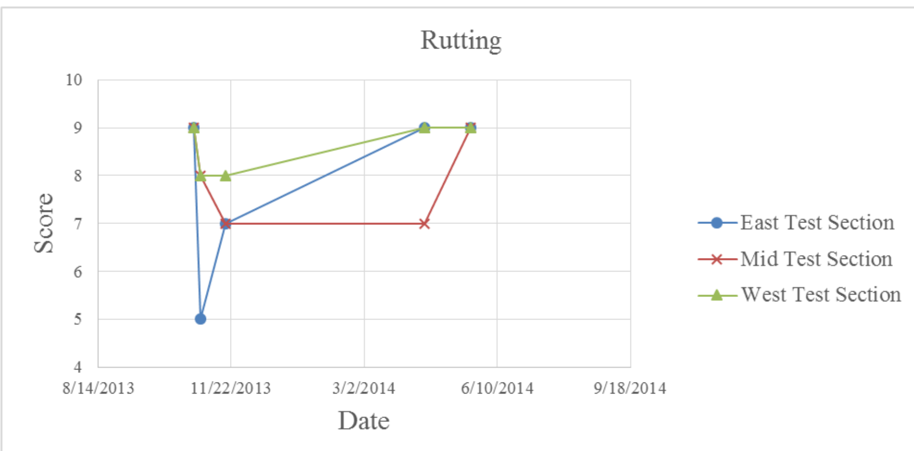

Loose Aggregate
10
9
8
7
6
5
4
3
2
Score
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
Date
North Section/Test Section 1
Mid Section/Test Section 2
South Section/Test Section 3

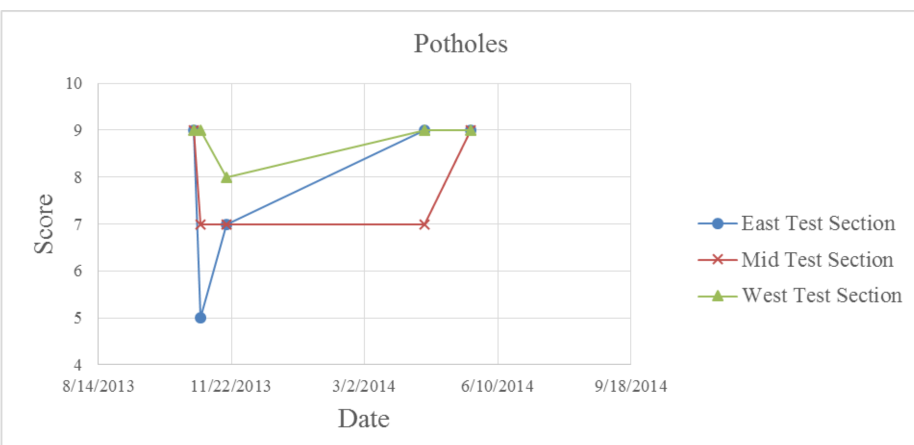

Dust
3
2
1
0
Score
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
Date
North Section/Test Section 1
Mid Section/Test Section 2
South Section/Test Section 3

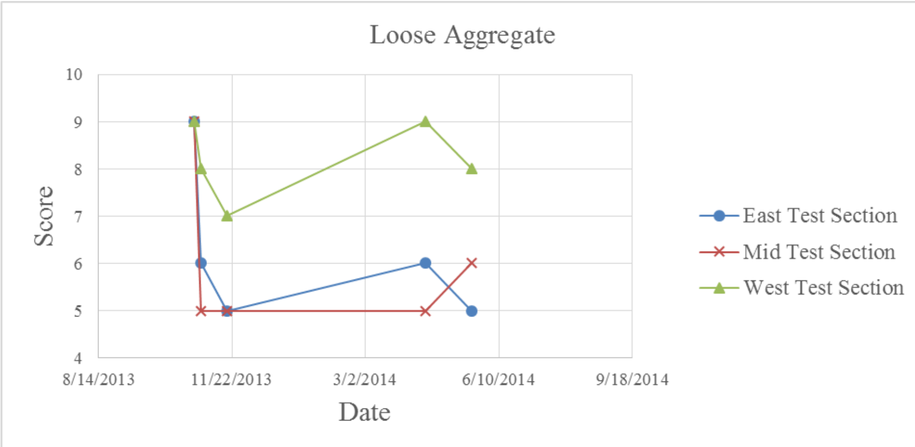

Crown
3
2
1
0
Score
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
Date
North Section/Test Section 1
Mid Section/Test Section 2
South Section/Test Section 3

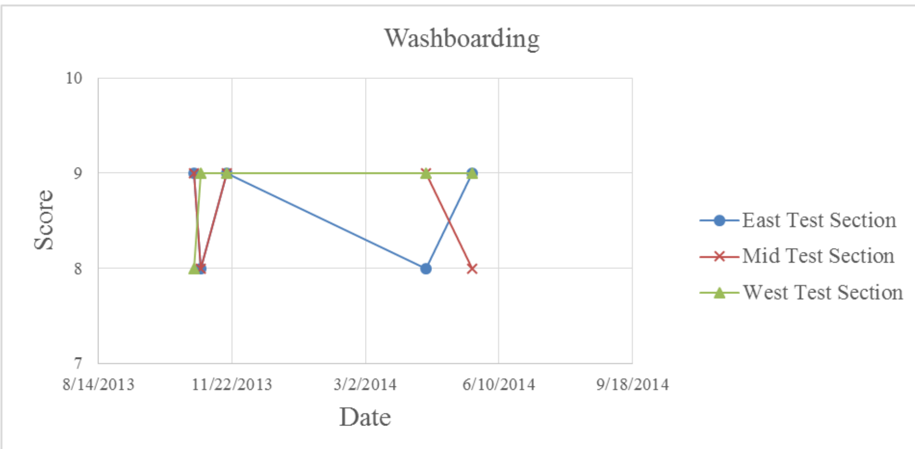


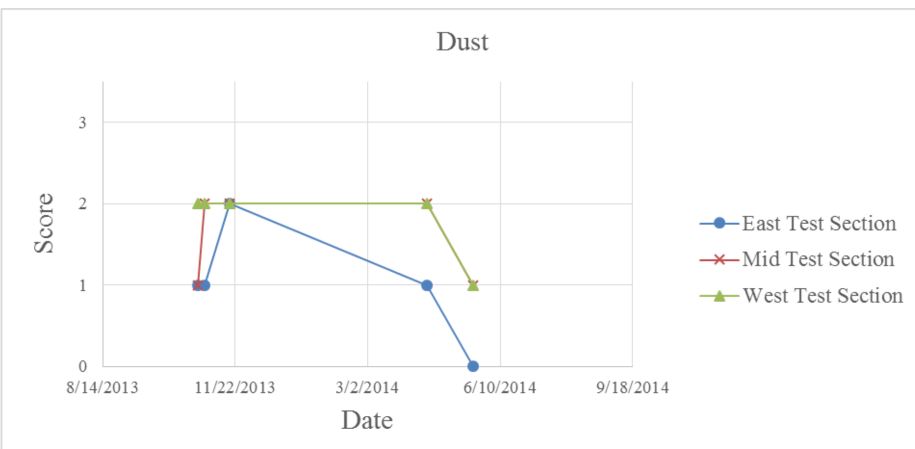
JACKSON COUNTY

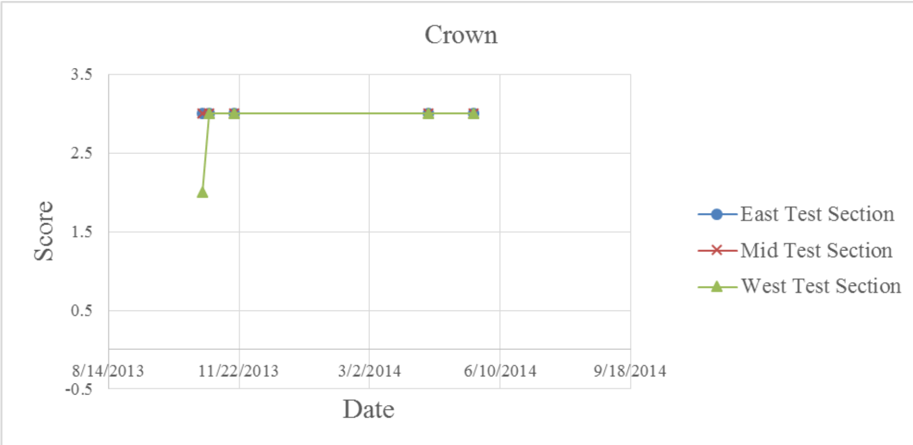


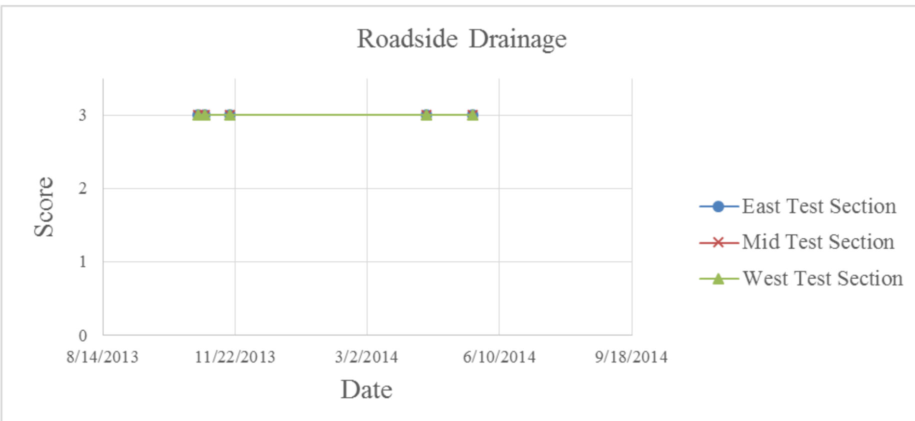



Loose Aggregate
Score
Date
10
9
8
7
6
5
4
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
East Test Section
Mid Test Section
West Test Section

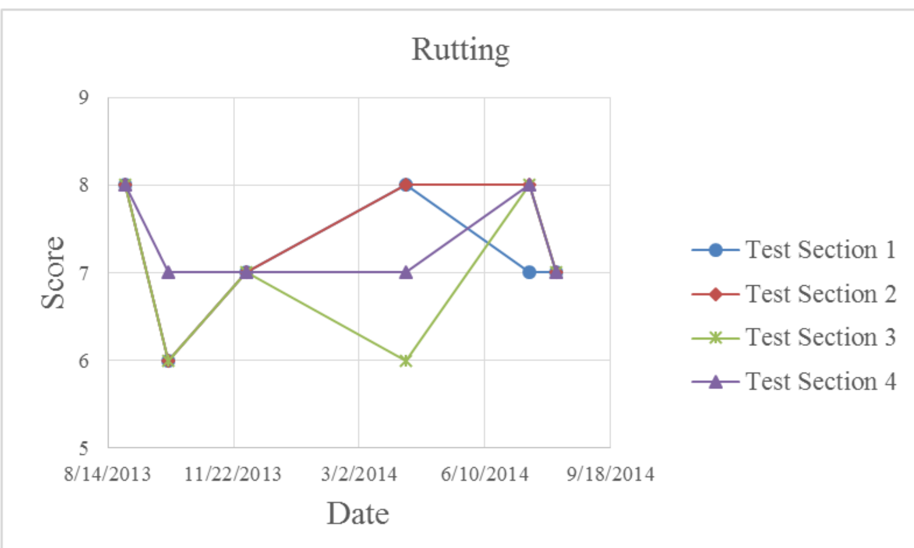

Washboarding
Score
Date
10
9
8
7
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
East Test Section
Mid Test Section
West Test Section

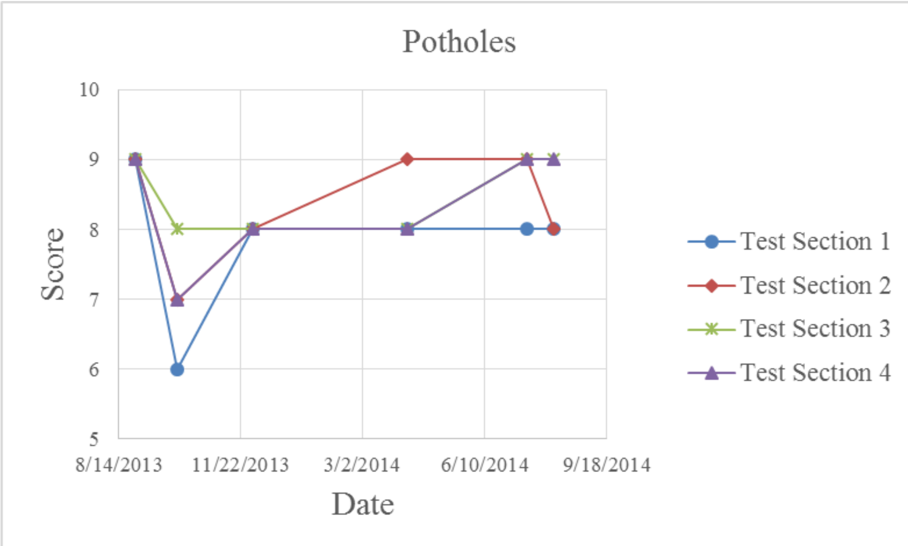

Dust
Score
Date
3
2
1
0
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
East Test Section
Mid Test Section
West Test Section

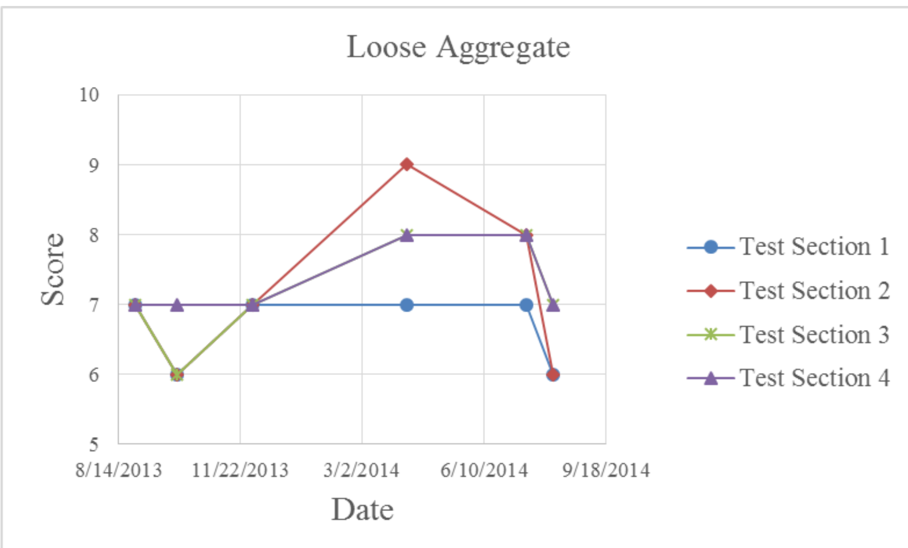


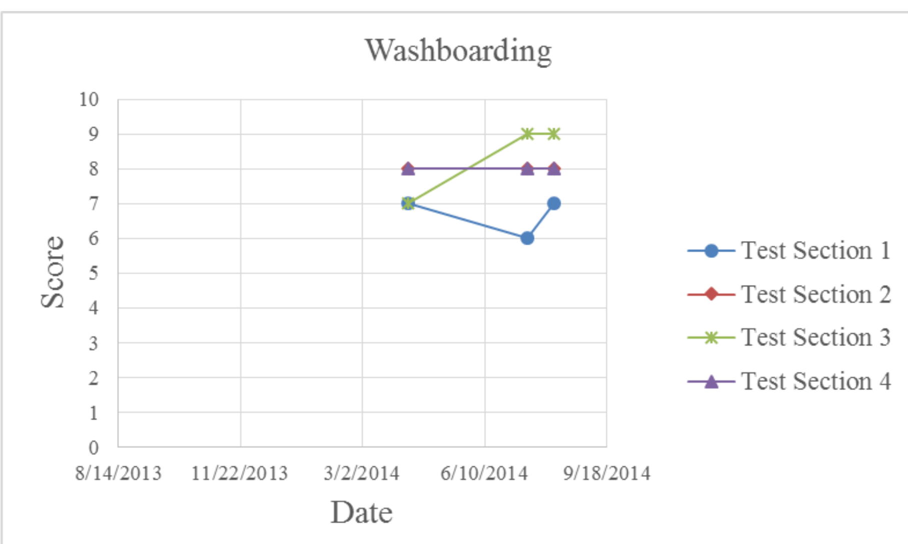


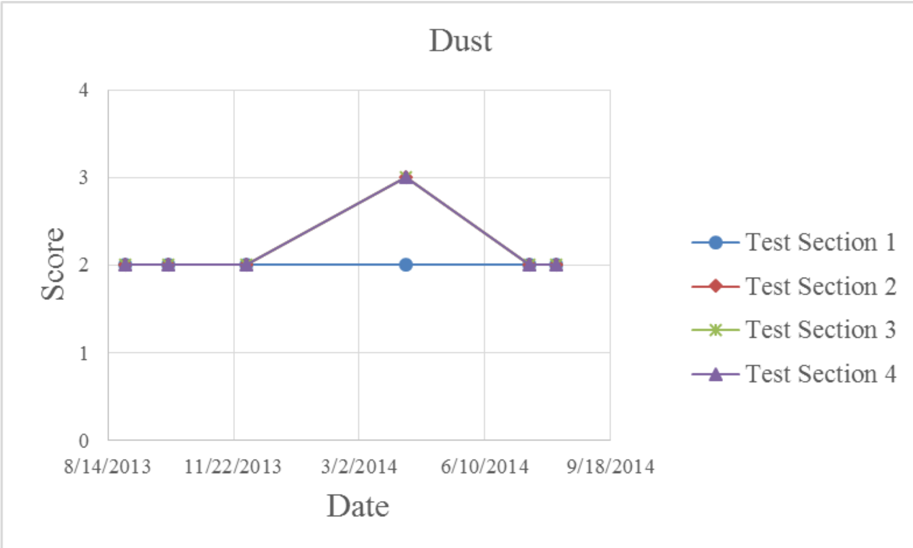
OLMSTED COUNTY

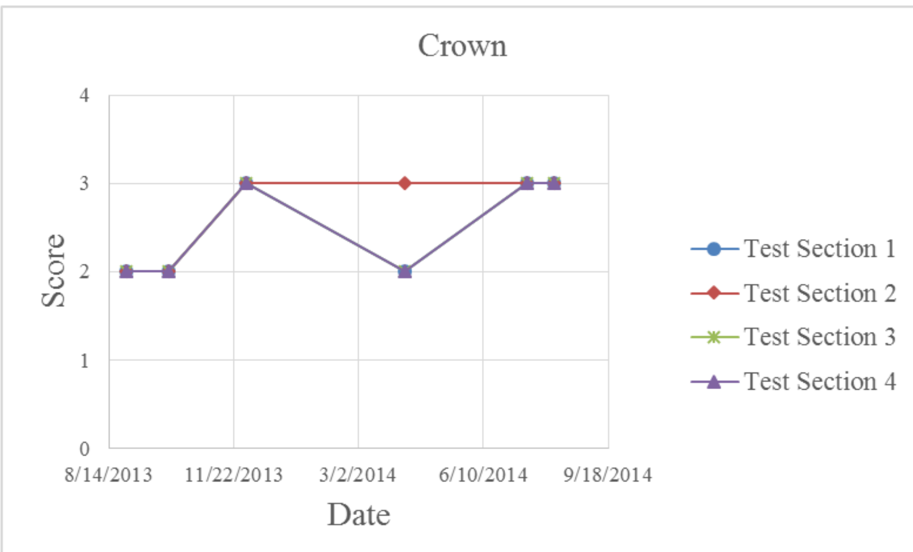


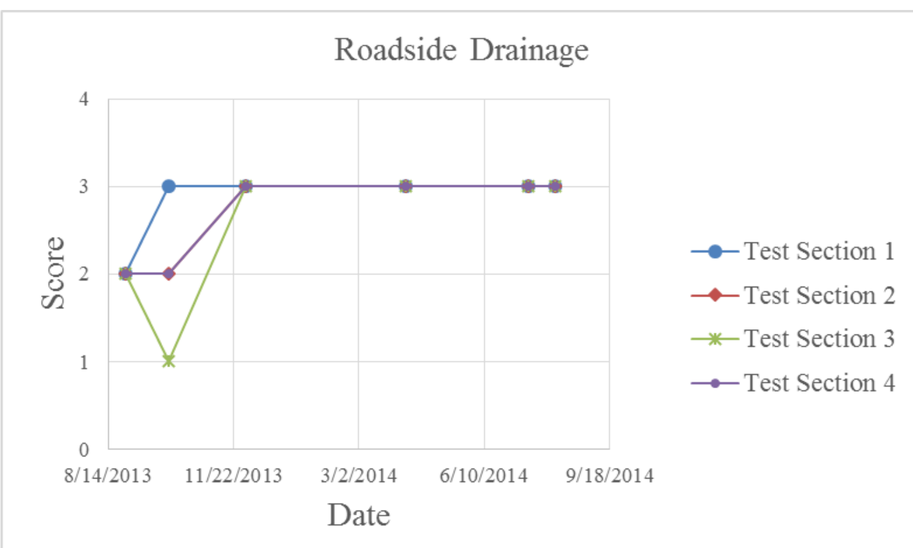

Potholes
10
9
8
7
6
5
Score
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
Date
Test Section 1
Test Section 2
Test Section 3
Test Section 4


Loose Aggregate
10
9
8
7
6
5
Score
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
Date
Test Section 1
Test Section 2
Test Section 3
Test Section 4


Washboarding
10
9
8
7
6
5
4
3
2
1
0
Score
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
Date
Test Section 1
Test Section 2
Test Section 3
Test Section 4


Dust
Score
Date
4
3
2
1
0
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
Test Section 1
Test Section 2
Test Section 3
Test Section 4


Crown
Score
Date
4
3
2
1
0
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
Test Section 1
Test Section 2
Test Section 3
Test Section 4


Roadside Drainage
Score
Date
4
3
2
1
0
8/14/2013
11/22/2013
3/2/2014
6/10/2014
9/18/2014
Test Section 1
Test Section 2
Test Section 3
Test Section 4

APPENDIX F: COST INFORMATION

BELTRAMI COUNTY

Material Cost—CR23

North Section/1st Section		
Amount of Material	498.00	ton per mile
Cost of Material	$ 6,225.00	per mile

Mid Section/2nd Section		
Amount of Material	249.00	ton per mile
Cost of Material	$ 2,988.00	per mile

South Section/3rd Section		
Amount of Material	150.00	ton per mile
Cost of Material	$ 1,800.00	per mile

Labor and Equipment Cost—CR23

	North Section/1st Section	Mid Section/2nd Section	South Section/3rd Section
Motor Grader+Operator	$ 421.79	$ 562.38	$ 281.19
Truck+Operator	$ 1,867.14	$ 1,867.14	$ 1,244.76
Water Truck+Operator	$ -	$ -	$ -
Rubber Tired Roller +Operator	$ -	$ -	$ -

JACKSON COUNTY

Material Cost—CR76

West Section/1st Section		
Amount of Material	200.64	ton per mile
Cost of Material	$ 1,103.52	per mile

Mid Section/2nd Section		
Amount of Material	126.72	ton per mile
Cost of Material	$ 982.08	per mile

East Section/3rd Section		
Amount of Material	73.92	ton per mile
Cost of Material	$ 572.88	per mile

Labor and Equipment Cost—CR76

	West Section/1st Section	Mid Section/2nd Section	East Section/3rd Section
Motor Grader+Operator	$ 382.04	$ 477.54	$ 447.54
Truck+Operator	$ 2,540.00	$ 1,905.00	$ 1,058.33
Water Truck+Operator	$ -	$ -	$ -
Rubber Tired Roller +Operator	$ -	$ -	$ -

OLMSTED COUNTY

Material Cost—CR115

	Section 1- Cl 5	
Amount of Material	1234.31	ton per mile
Cost of Material	$ 8,430.35	per mile

	Section 2- 2/3Cl5+1/3Lime	
Amount of Material	1156.26	ton per mile
Cost of Material	$ 7,722.18	per mile

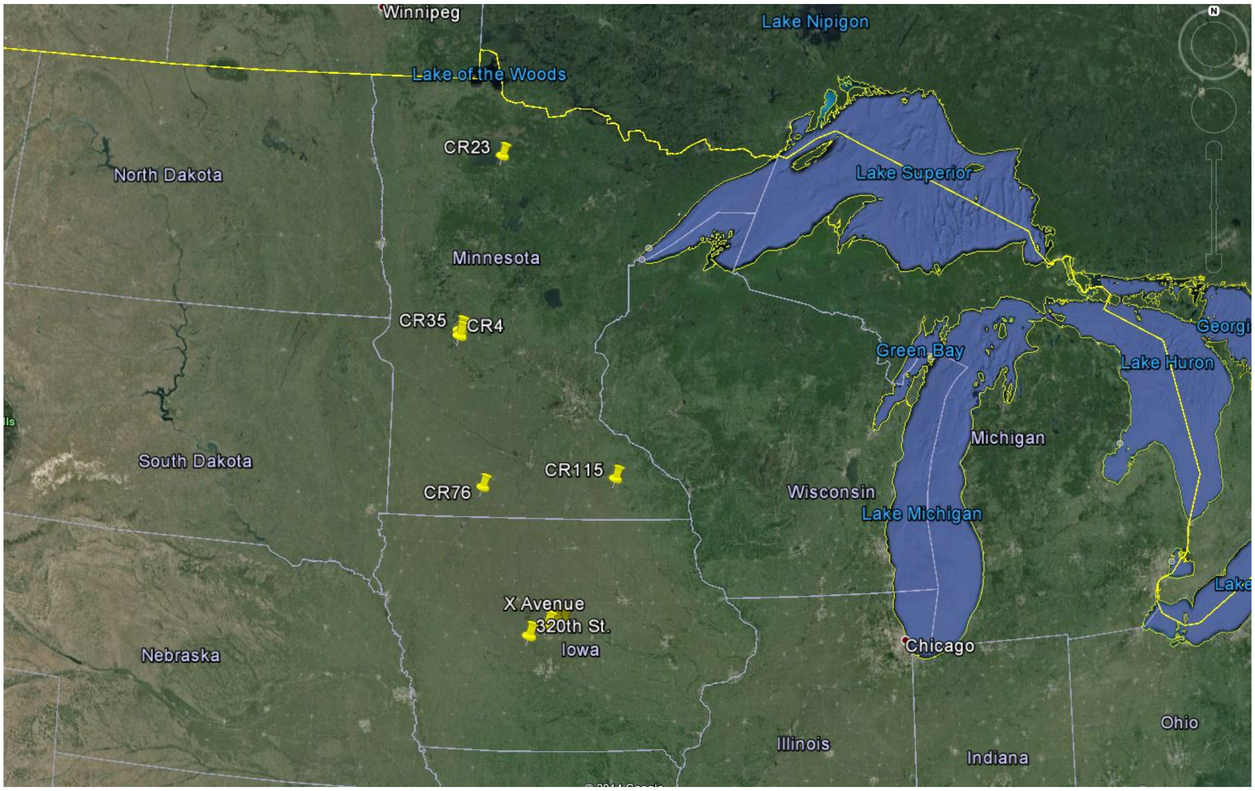
	Section 3- 1/2Cl5+1/2Cl2	
Amount of Material	1283.04	ton per mile
Cost of Material	$ 8,763.16	per mile

	Section 4- Cl2	
Amount of Material	1411.49	ton per mile
Cost of Material	$ 9,640.44	per mile

Labor and Equipment Cost—CR115

	Section 1- Cl5	Section 2- 2/3Cl5+1/3Lime	Section 3- 1/2Cl5+1/2Cl2	Section 4- Cl2
Motor Grader+Operator	$ 1,181.25	$ 945.00	$ 1,299.38	$ 1,417.50
Truck+Operator	$ 11,000.00	$ 8,800.00	$ 12,100.00	$ 13,200.00
Water Truck+Operator	$ 1,375.00	$ 1,100.00	$ 1,512.50	$ 1,650.00
Rubber Tired Roller +Operator	$ 1,250.00	$ 1,000.00	$ 1,375.00	$ 1,500.00

APPENDIX G: AGGREGATE SAMPLE ORIGIN MAP

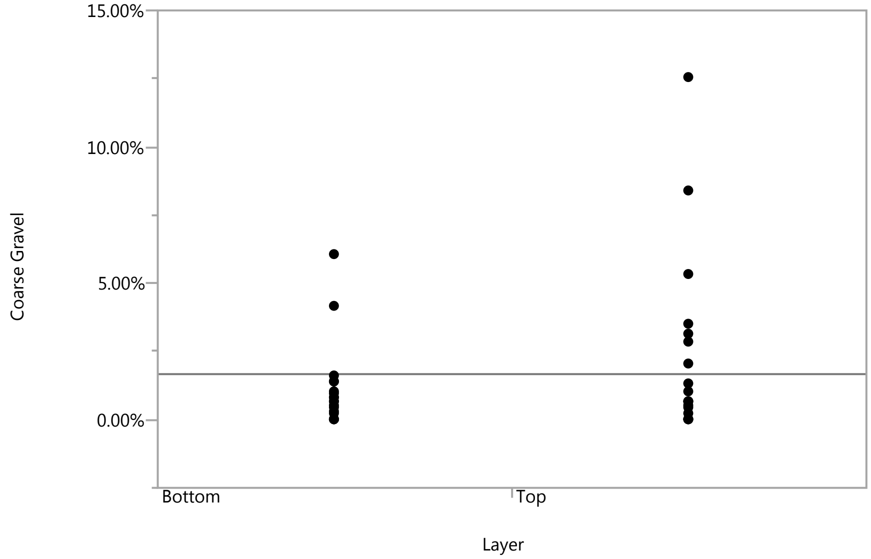


APPENDIX H: SOIL CLASSIFICATION

Sample		USCS Classificiation Top	USCS Classificiation Bottom
IA	Story County, 160th, collected 11/14/13, top 1 in., bottom 2 in.	GW Gravel with Sand	SM Sand with Gravel
	Boone County, X Ave., collected 11/14/13, top 1 in., bottom 2 in.	SW Sand with Gravel	SW-SM Sand with Silt and Gravel
	Boone County, 150th, collccted 11/14/13, top 1 in., bottom 1.5 in.	SP-SM Sand with Silt and Gravel	SW-SM Sand with Silt
	Boone County, 320th, collected 11/14/13, top 1 in., bottom 2 in.	GW Gravel with Sand	SP-SM Sand with Silt and Gravel
MN	Beltrami, CR23, collected 8/22/13, top 1 in., bottom 2 in.	SW Sand with Gravel	SP-SM Sand with Silt
	Pope, CR35 #1, collected 8/23/13, top 1.5 in., bottom 2 in.	SP-SM Sand with Silt and Gravel	SP-SM Sand with Silt and Gravel
	Pope, CR35 #2, collected 8/23/13, top 1.5 in., bottom 2 in.	SP Sand with Gravel	SP-SM Sand with Silt and Gravel
	Pope, CR35 #3, collected 8/23/13, top 1.5 in., bottom 2 in.	SP Sand With Gravel	SW-SM Sand with Silt
	Olmsted, North CR115, collected 8/20/2013, top 1.5in, bottom 2in.	GP-GM Gravel with Silt and Sand	SM Silty Sand with Gravel
	Olmsted, South CR115, collected 8/20/2013, top 1.5in, bottom 2in.	GP-GM Gravel with Silt and Sand	SM Silty Sand with Gravel
	Jackson, CR76, collected 10/24/13, top 1 in., bottom 2 in.	SW Sand with Gravel	SM with Gravel
	Pope, CR4, collected 7/21/13, Top 1 in., bottom 2 in.	GW Gravel with Sand	SM Silty Sand with Gravel
Post Construction			
MN	Olmsted, Test Section #1, collect 8/8/2014, top 1 in., bottom 2 in.	GP Gravel	SM with Gravel
	Olmsted, Test Section #2, collect 8/8/2014, top 1 in., bottom 2 in.	SP with Gravel	GC with Sand
	Olmsted, Test Section #3, collect 8/8/2014, top 1 in., bottom 2 in.	GP with Sand	GC with Sand
	Olmsted, Test Section #4, collect 8/8/2014, top 1 in., bottom 2 in.	GP with Gravel	SM with Gravel
	Beltrami, Test Section #1, collect 8/8/2014, top 1 in., bottom 2in.	SW with Gravel	SM with Gravel
	Beltrami, Test Section #2, collect 8/8/2014, top 1 in., bottom 2in.	GP with Gravel	SM with Silty Sand
	Beltrami, Test Section #3, collect 8/8/2014, top 1 in., bottom 2in.	SP with Gravel	SP-SM with Silt

APPENDIX I: INDEPENDENT T-TEST RESULTS

Oneway Analysis of Coarse Gravel By Layer

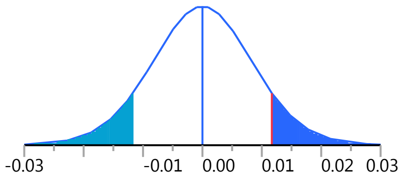


t Test

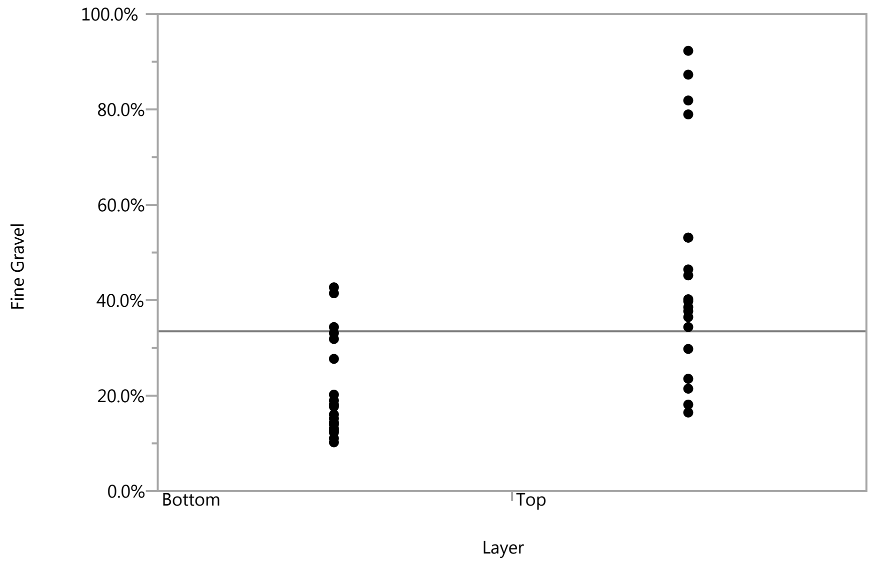
Top-Bottom

Assuming unequal variances

Difference	0.01168	t Ratio	1.401478
Std Err Dif	0.00834	DF	25.25028
Upper CL Dif	0.02885	Prob > |t|	**0.1732**
Lower CL Dif	-0.00548	Prob > t	0.0866
Confidence	0.95	Prob < t	0.9134



Oneway Analysis of Fine Gravel By Layer

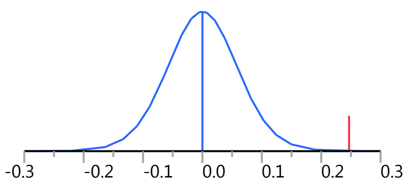


t Test

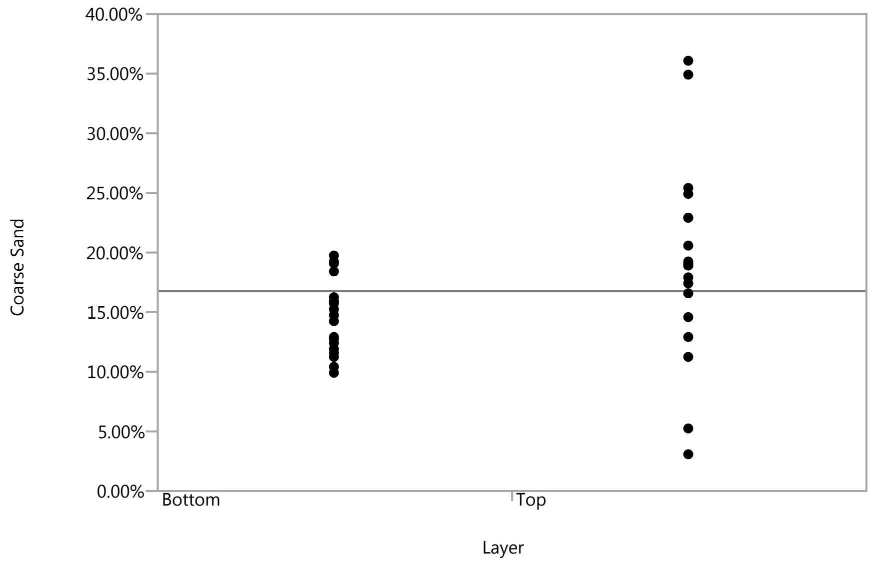
Top-Bottom

Assuming unequal variances

Difference	0.246895	t Ratio	4.216605
Std Err Dif	0.058553	DF	24.93888
Upper CL Dif	0.367502	Prob > |t|	**0.0003***
Lower CL Dif	0.126288	Prob > t	0.0001*
Confidence	0.95	Prob < t	0.9999



Oneway Analysis of Coarse Sand By Layer

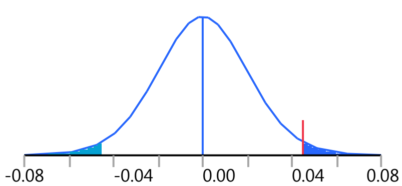


t Test

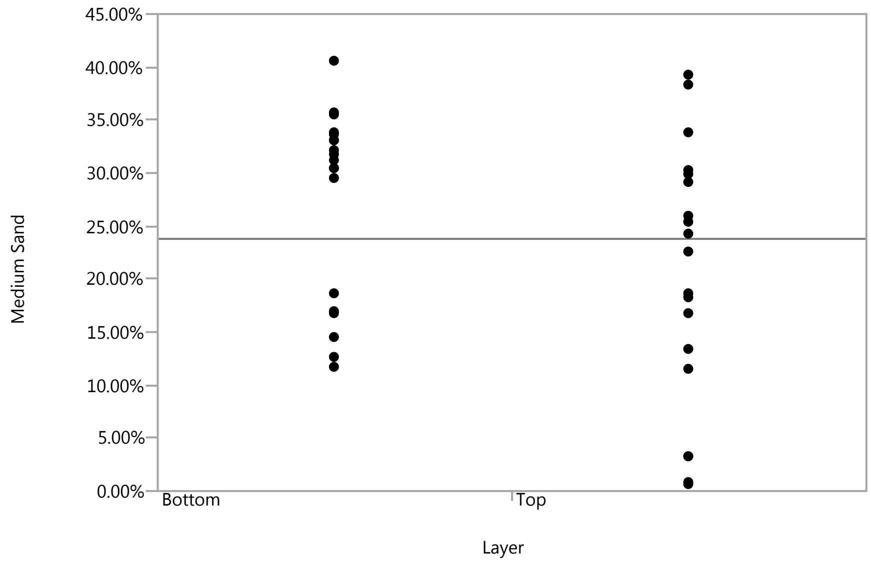
Top-Bottom

Assuming unequal variances

Difference	0.044947	t Ratio	2.227186
Std Err Dif	0.020181	DF	22.91796
Upper CL Dif	0.086704	Prob > |t|	**0.0360***
Lower CL Dif	0.003191	Prob > t	0.0180*
Confidence	0.95	Prob < t	0.9820



Oneway Analysis of Medium Sand By Layer

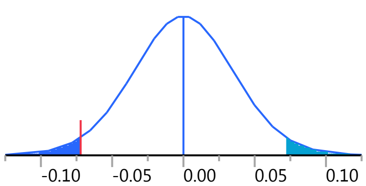


t Test

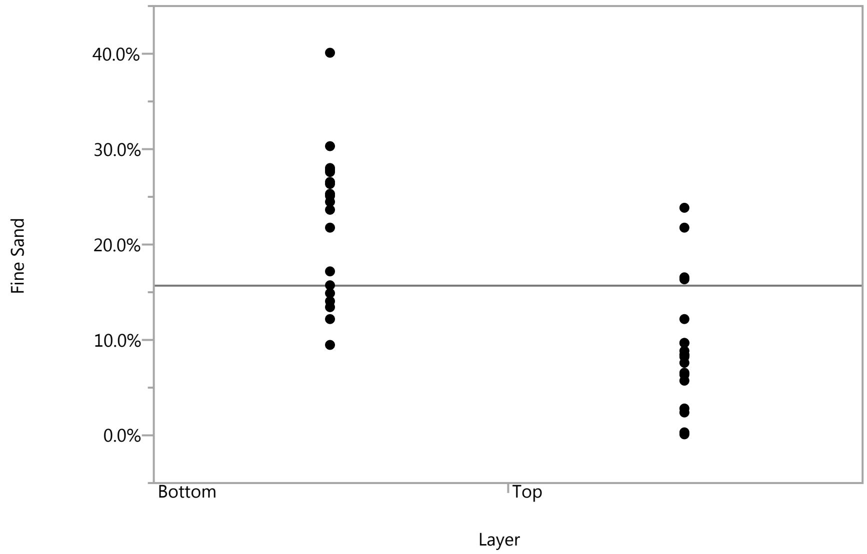
Top-Bottom

Assuming unequal variances

Difference	-0.07211	t Ratio	-2.06681
Std Err Dif	0.03489	DF	33.03872
Upper CL Dif	-0.00113	Prob > |t|	**0.0467***
Lower CL Dif	-0.14308	Prob > t	0.9767
Confidence	0.95	Prob < t	0.0233*



Oneway Analysis of Fine Sand By Layer

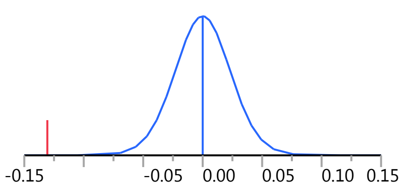


t Test

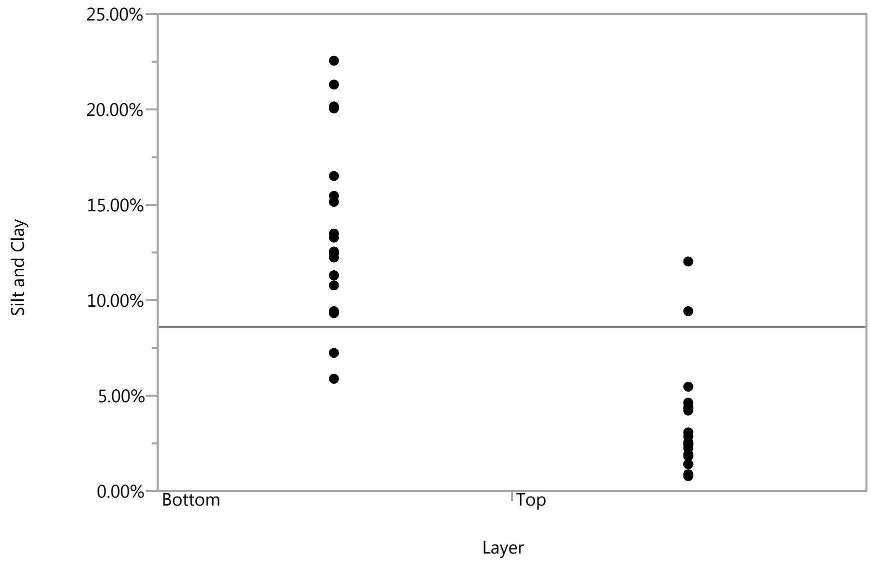
Top-Bottom

Assuming unequal variances

Difference	-0.13063	t Ratio	-5.6338
Std Err Dif	0.02319	DF	35.01097
Upper CL Dif	-0.08356	Prob > |t|	**<.0001***
Lower CL Dif	-0.17770	Prob > t	1.0000
Confidence	0.95	Prob < t	<.0001*



Oneway Analysis of Silt and Clay By Layer

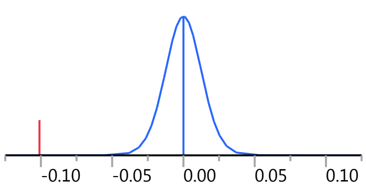


t Test

Top-Bottom

Assuming unequal variances

Difference	-0.10100	t Ratio	-7.98802
Std Err Dif	0.01264	DF	29.82673
Upper CL Dif	-0.07517	Prob > |t|	**<.0001***
Lower CL Dif	-0.12683	Prob > t	1.0000
Confidence	0.95	Prob < t	<.0001*



APPENDIX J: CALCULATION OF THE AMOUNT OF CRUSHER DUST NEEDED

The Particle Size Distribution (PSD) curves of top and bottom wearing material encompass an area that suggests the gradation difference. The research conjecture that the approach of the PSD curve of the top material to that of the bottom could possibly fix the problem, considering that the bottom material is firmly bound-down. A calculation procedure is described in this section, using CR76, Jackson County as the example.

Gradation of sample of the top material can be used as the representative for the problematic surface, Table 1. Gradation of crusher dust is available from the supplier, Table 2. Resultant gradation of mixing crusher dust into representative top material can be mathematically determined.

By knowing the gradation of crusher dust, Table 2, actual weight for each size can be calculated when 1:1 mix was proposed. In this case, 1718.8g representative top material will mix with 1718.8g crusher dust. Table 3 shows the resultant gradation after mixing. PSD of resultant material was exhibited in Figure 1. In order to determine the difference between the resultant PSD curve and that of the bottom material, a variance index (VI) was introduced. The index is an aggregate of vertical percentage differences at all sieve size used. Assume percentage passing for each sieve size is respectively   for resultant PSD curve and   for bottom PSD curve. Expression below is used to calculate the VI.

A trial calculation was performed with different mixing ratios and corresponding VIs were obtained and summarized in Table 4. The result suggests that using 0.6:1 ratio, 3/5 of the amount of top material existing, would provide the closest PSD curve to that of the bottom material.

Table 15 Gradation of Top Material-CR76, Jackson County

U.S. Sieve Size	Aver.	Weight Retained (%)	Weight Passing (%)
1.5"	0.00	0.0%	100.0%
1"	0.00	0.0%	100.0%
3/4"	17.95	1.0%	99.0%
3/8"	191.55	10.7%	88.3%
#4	192.65	10.7%	77.6%
#10	338.75	18.9%	58.7%
#40	687.15	38.3%	20.4%
#200	290.75	16.2%	4.2%
<#200	71.60	4.2%	0.0%
Total (g)	1718.80	100%	

Table 16 Gradation of Crusher Dust in Jackson County

Gradation of To-add Material		
	Weight Retained (%)	Weight Passing (%)
U.S. Sieve Size		
1.5"	0.0%	100.0%
1"	0.0%	100.0%
3/4"	0.0%	100.0%
3/8"	0.0%	100.0%
#4	0.6%	99.4%
#10	40.3%	59.2%
#40	32.3%	26.9%
#200	17.6%	9.2%
<#200	9.2%	0.0%

Table 17 Gradation of Resultant Material

Coefficient	1.00	1718.80	
Add	End Material	Weight Retained	Weight Passing
0.00	0.00	0.00%	100.00%
0.00	0.00	0.00%	100.00%
0.00	17.95	0.51%	99.49%
0.00	191.55	5.43%	94.06%
10.14	202.79	5.75%	88.31%
691.82	1030.57	29.22%	59.09%
555.17	1242.32	35.23%	23.86%
303.02	593.77	16.84%	7.02%
158.65	230.25	7.02%	0.00%
	3278.95	100.00%	

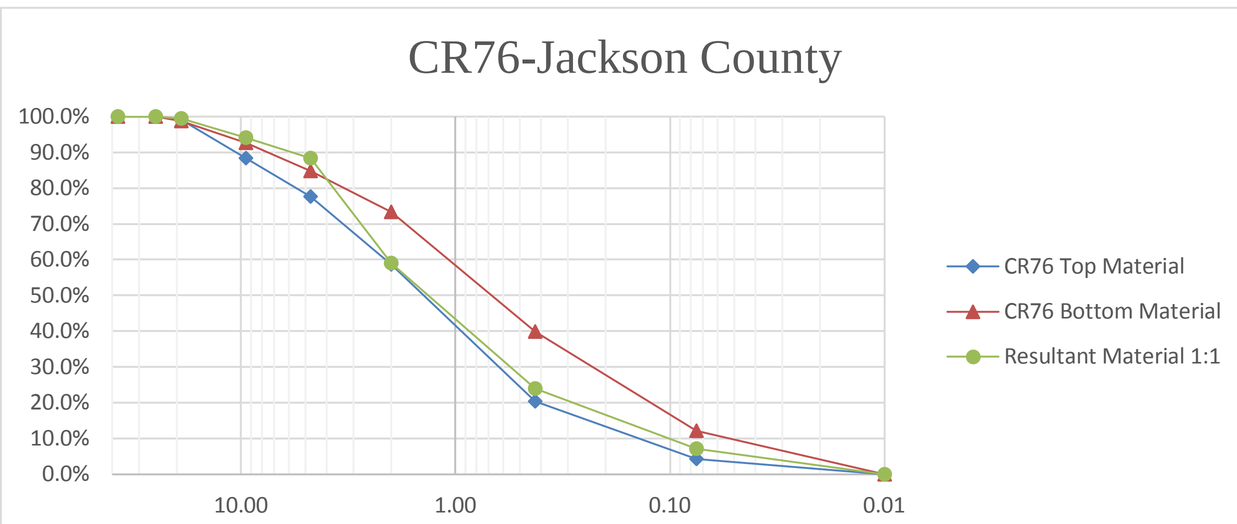


Figure 75 Resultant PSD-CR76 Jackson County

Table 18 Variance Index Table-CR76, Jackson County

		Variance Index (VI)
Ratio	1.00	0.41
	0.80	0.40
	0.60	0.39
	0.40	0.41
	0.20	0.47

APPENDIX K: FINDING SUMMARY TABLE

	Section	Significant cross section deterioration	Distress				Roughness (<2.2=good)	Amount of gravel loss (cy/mi)	Elevation change (ft)	Loose aggregate amount (ton/mi)	Benefit-cost analysis (five-year cycle)
			Rutting	Washboa	Potholes	Loose aggregate					
Jackson	Section#1 (control)	NO	Good	Good	Good	Good	NA	9.80	-0.09	67.98	N/A
	Section#2 (experiment)	NO	Good	Good	Good	Fair	NA	75.20	-0.20	96.99	
	Section#3 (experiment)	YES	Good	Good	Good	Fair	NA	120.10	-0.37	96.53	
Beltrami	Section#1 (control)	NO	Good	Good	Good	Good	1.30	20.20	-0.05	47.59	$ 12,680.83
	Section#2 (experiment)	NO	Good	Good	Good	Good	1.30	24.70	-0.06	51.70	$ 10,278.91
	Section#3 (experiment)	NO	Good	Fair	Good	Fair	1.26	35.20	-0.09	59.38	$ 10,270.29
Olmsted	Section#1 (control)	NO	Good	Fair	Good	Fair	2.12	86.00	-0.19	69.72	N/A
	Section#2 (experiment)	NO	Good	Good	Good	Good	1.99	104.20	-0.24	60.59	
	Section#3 (experiment)	NO	Good	Good	Good	Good	2.17	65.80	-0.10	61.50	
	Section#4 (control)	YES	Good	Good	Good	Good	1.70	93.80	-0.28	63.11	