Development of Granular Roads Asset Management System

Final Report
November 2019

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16. Abstract

Granular roads account for more than 75% of roads managed by Iowa counties. Granular roads experience rapid deterioration and more quickly develop various localized problems compared to paved roads. Frequent and regular maintenance is needed to keep the roadway performance at a desired reliability over its lifetime. Current granular road asset management practices are primarily on an ad hoc and reactive basis, which may not be the most efficient approach. The lack of a reliable and practical tool to estimate gravel loss over time, and thus the required amount of aggregate (rock) that needs to be purchased, is one of the major problems that local agencies currently face.

This research project developed a data-driven Granular Roadway Asset Management System (GRAMS) to assist local agencies in making more reliable gravel loss estimates and consequently determining annual aggregate (rock) requirements for proper budgeting purposes. In this study, a series of online and in person meetings and interviews were conducted along with electronic mailing surveys to gather information to develop a Microsoft Excel-based user-friendly GRAMS.

Advanced statistical analysis methods such as the beta regression model and survival analysis were used as computational algorithms for estimation and risk analysis. When the user enters several input values, the GRAMS can generate a range of estimates for varying budget conditions and different levels of service. The tool is expected to significantly help local agencies to obtain consistency in terms of estimating gravel loss and determining aggregate (rock) requirements, and as a result, they can better defend their granular road maintenance budget requests and management. This tool is primarily based upon empirical data, and further calibration is recommended for enhanced estimation.

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EXECUTIVE SUMMARY

More than 75% of Iowa secondary roads are granular roads. These granular roads serve as lifelines for local and remote communities in Iowa. Thus, maintaining an acceptable reliability of these roadways is critical. However, due to the lack of a reliable tool for estimating future granular road maintenance needs, counties have been struggling to determine their annual aggregate (rock) requirements and thus request an appropriate maintenance budget allocation for their granular roads.

Unlike asphalt or concrete pavements, granular roads deteriorate faster and more quickly develop localized failures due to changing weather conditions and patterns, poor aggregate (rock) material quality, drainage issues, unusual traffic patterns, and subgrade soil quality-related issues. Thus, it is difficult to predict deterioration patterns and estimate maintenance needs at an individual segment level for granular roads. In order to quickly and flexibly respond to localized repair, maintenance, and resurfacing needs, local agencies would like to have an agency-level (or network-level) gravel loss estimation tool to determine annual rock requirements.

To address this need, this project developed a Microsoft Excel-based Granular Roadway Asset Management System (GRAMS). The GRAMS can estimate gravel loss over time for an entire network managed by a local agency and determine annual rock requirements in terms of tons per mile (TPM), along with providing estimated costs and risk curves under different levels of service scenarios.

The GRAMS generates estimates when several input values are entered. The mandatory input values are county name, roadway system properties such as (length, width, and condition) and unit costs (material, hauling, transportation, dump truck, and miscellaneous). Optional input values include rock material properties (Los Angeles abrasion and percent fines values), desired levels of service, and a range of maintenance options. As part of the GRAMS development, an advanced statistical method including beta regression analysis was used to develop a gravel loss estimation model, and survival analysis was used to estimate the annual rock requirements based on the estimated annual gravel loss values.

Most local agencies in Iowa have been using their previous experience and quick visual inspections to estimate annual gravel loss and aggregate (rock) requirements. Thus, the GRAMS is expected to significantly help local agencies to better maintain and manage their granular roads by providing a user-friendly tool, while also helping them to defend their estimated materials needs and budget requests.

This report includes a comprehensive literature review on granular road asset management methods in other states and countries. It also includes survey analysis results to show the current status of granular road asset management practices in Iowa counties.

CHAPTER 1. INTRODUCTION

Overview

About 67,000 of the 90,000 miles of Iowa's secondary roads consist of granular roads (Office of Analytics, Iowa DOT 2019). Thus, the sustainability of granular roadways is very important to Iowa's rural economy, since these roads provide access to local farms and enable the transportation of agricultural products. Interruption in access to these granular roadways can have a significant impact on agricultural productivity and therefore the rural economy. Ineffective maintenance of such roads poses significant health and physical risks as well (Anderson and Gesford 2007). In Iowa, such risks are higher by a wide margin, since the state consists of granular roads at more than twice the national average of 33% (Bureau of Transportation Statistics 2018).

Granular roads typically consist of two layers: the granular surface and the subgrade. Geomaterials used in the granular surface layers are responsible for distributing wheel loads uniformly to the subgrade layer in order to protect the subgrade layer from excessive stress at a single location and ultimately increase the service life of roads (Xiao et al. 2012). It is well known that most failures in unpaved roads occur due to the lack of required geotechnical properties in their granular surface layers (Haider et al. 2014). The problems commonly encountered with granular roads are: (1) unsuitable material usage, (2) inadequate material distribution, (3) surface deterioration through aggregate loss, (4) surface abrasion, and (5) ineffective drainage.

Granular roads deteriorate rapidly compared to paved roads. Truck traffic, precipitation and environmental conditions, quality of the aggregate (rock) materials, and subgrade soil quality are considered to play key roles in deterioration. Proper maintenance enables roadway systems to provide a desired reliability. However, ad hoc and reactive maintenance strategies are common for granular roads, as they serve smaller amounts of traffic compared to paved roads, and local agencies constantly struggle with limited budget allocations for granular road maintenance.

To date, there are no readily available tools that can help local agencies to systematically evaluate granular road performance degradation over time, estimate gravel loss, and determine the required amount of aggregate (rock) to maintain their granular road system at an acceptable service level. As a result, local agencies face difficulties when asked to justify their granular road maintenance budgets.

Construction and maintenance of granular roadways can account for as much as 28% of a county's budget. This cost includes only the granular materials purchase and excludes transport, placement, and grading. Thus, it is important to develop a structured method to assist local agencies in optimizing a county's granular road asset maintenance strategy. The Iowa County Engineers Association Service Bureau (ICEASB) developed a preliminary Granular Road Asset Management System (GRAMS) as a partial fulfilment of the Iowa Transportation Asset Management (ITAM) steering committee mission, which is to (1) find better ways to "tell the story" about asset management needs and (2) identify methods and procedures that could be adopted by road agencies. The concept of this preliminary GRAMS system has been tested and positively received by several county engineers.

This research project used the preliminary GRAMS as its basis and built a more robust tool that can facilitate the process of estimating the expected level of deficiency in upcoming years in terms of rock requirements, and therefore, to a greater extent enable local agencies to make engineering-based roadway maintenance decisions. This tool can simulate roadway deficiencies under various conditions and predict the performance for varying magnitudes of treatment. Therefore, it enables county engineers to reasonably estimate the aggregate (rock) requirements under different budget scenarios.

The GRAMS has been developed considering the following major factors: (1) quality measures of the granular materials, such as Los Angeles abrasion and gradation characteristics (fines content), (2) effective crust thickness, (3) drainage capacity, (4) subgrade conditions (which are calculated based on properties such as liquid limit, plasticity index, silt and clay content, moisture content, shrink-swell potential, and depth of the ground water table), and (5) historical performance and operations data.

Research Objectives

The goal of this project was to develop a Microsoft Excel-based GRAMS tool as a decision-support and communication-of-strategy tool for local agencies in Iowa. To accomplish this overarching goal, the research team successfully completed the following objectives.

1. Collect and synthesize the granular road performance and cost data.
2. Develop a material-quality indexing method to effectively predict the anticipated long-term performance of different materials properties used for granular roads.
3. Improve the previously developed method (or develop a formula) to estimate annual replacement needs in tons-per-mile (TPM) and the total tons needed for a particular local granular roadway system, based on a set of input parameters, such as a material quality index related to the rate of material loss, traffic volume and loading estimates, widths of roadways, weathering losses, crown and drainage, etc.
4. Develop a method to determine the amount of serviceable material present in a granular road’s crust at any given time (i.e., the rock-in-service [RIS] TPM tool).
5. Develop a probabilistic method based on the actual field data to quantify and estimate the risk that a granular road may fall below the minimum acceptable reliability when adverse subgrade conditions develop, with the amount of serviceable material in the crust measured in TPM as a main input parameter.
6. Develop a model to predict the system-wide risks and gravel needed in TPM in order to manage the risks.
7. Develop a comprehensive GRAMS by integrating methods and formulas developed from the previous objectives into a Microsoft spreadsheet and web-based platform. This GRAMS tool should be able to generate the most optimal maintenance strategy (maximum TPM, minimum TPM, and annual replacement rate) that can keep the risk of impaired road performance below a target maximum level over multiple years.

Organization of the Report

This report includes six chapters. Chapter 1 describes the research background and objectives. Chapter 2 provides a brief summary on the previous work on granular roadway deterioration and management policies. Chapter 3 presents the current granular roadway management practices in Iowa. Chapter 4 explains the methodology used to develop the GRAMS tool. Chapter 5 provides a brief explanation of how to use the GRAMS tool interface. Chapter 6 presents the conclusions of this project and recommendations for future research. All supporting materials are presented in the appendices.

CHAPTER 2. LITERATURE REVIEW AND SUMMARY OF CURRENT PRACTICES

This chapter summarizes the literature on the current practices for granular roadway deterioration modeling and granular roadway management systems both nationally and internationally.

In a three-level roadway system hierarchy, granular roads serve primarily as tertiary roads as shown in Figure 2-1.

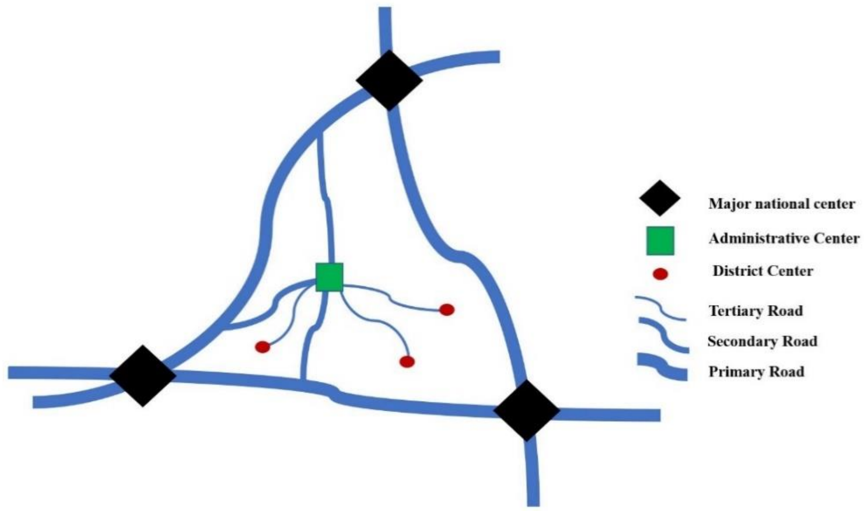


Figure 2-1. Functional hierarchy of roadway network

Such roads provide access and mobility to remote/rural populations, thus playing a key role in the socioeconomic development of geographically challenged locations, as evidenced in Lebo and Schelling (2001). Simultaneous advancements in the infrastructure system, social services, and agricultural sectors led to the overall development of remote communities, as shown in Figure 2-2.

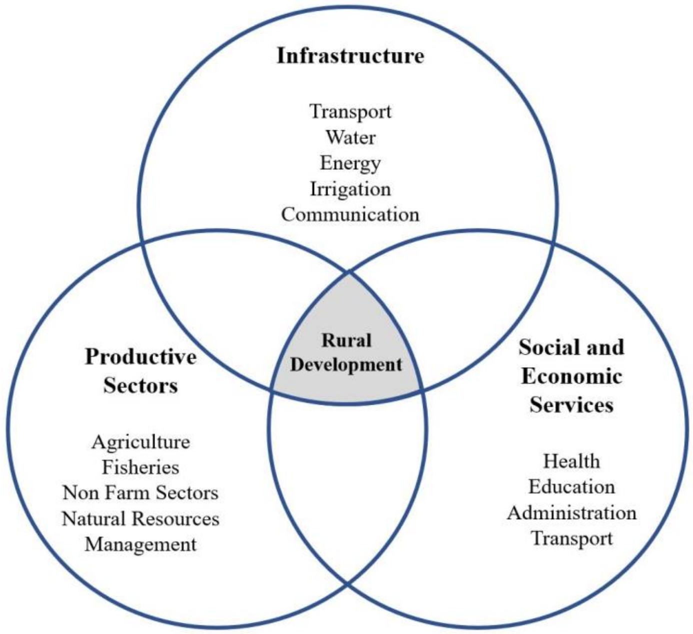


Figure 2-2. Elements of social development

Investment in granular roads improves accessibility to remote communities, which leads to social, economic, and financial growth, as evidenced by multiple studies conducted in China, India, Pakistan, Morocco, and Vietnam (Fan and Chan-Kang 2004, Fan et al. 1999, Levy 2004, Essakali 2005, Fan et al. 2004). For optimal long-term economic performance, granular roadway management systems should consider seven dimensions identified by the South African Development Community (SADC 2003), namely the political, social, institutional, technical, economic, financial, and environmental aspects. In contrast, however, the current state of granular roadway management practices is mainly focused on short-term results, and there has thereby been a significant lack in terms of practical life-cycle cost analysis tools, economic valuation and analysis techniques, and project prioritization approaches.

Granular Roadway Deterioration

Granular roadways deteriorate with time due to external influential factors such as repeated truck traffic and environmental loadings and internal influential factors such as varying aggregate (rock) quality, subgrade soil properties, and drainage conditions. Deterioration mechanisms cause both structural and functional defects in roadways. Common structural deficiencies involve rutting and potholes, whereas functional defects are dust generation, corrugations, gravel loss, loose aggregate, and erosion.

Regular maintenance activities keep roadway performance at a desired reliability throughout its lifetime. Maintenance work can range from routine activities (e.g., roadside, surface, and drainage maintenance) to minor and major road repair work. Local agencies are primarily responsible for maintaining granular roadways. Such roadways receive less attention in terms of maintenance funding compared to paved roads. In addition, local communities often struggle to provide the desired reliability in terms of granular roadway maintenance due to inadequate technical skills among roadway maintenance personnel and the unavailability of practical maintenance decision-making tools. Not only that, but local agencies often do not possess technologies for evaluating overall roadway network performance or the impact of maintenance treatment activities on social and economic conditions.

Deterioration modeling can assist in understanding granular roadway deterioration mechanisms and in predicting the effects of maintenance treatments. Roughness progression and gravel material loss modeling are two popular roadway deterioration modeling methods (Paterson 1991). This research project explores gravel loss modeling, since, in the US, roadway thickness plays a key role in maintenance decision-making.

Highway Development and Management (HDM-4) Model

The Highway Development and Management (HDM-4) model has been identified as one of the most effective gravel loss prediction models (Uys 2011). It was developed as a part of a World Bank study with numerous field experiments and investigations in South Africa. (Kerali 2000, Kerali et al. 2000, Wightman et al. 2000, Odoki and Kerali 2000). This model is promising for global-scale applications, since it introduced local calibration factors (Bennett and Paterson 2000). Thus, the model generates more realistic results when it is applied to specific regions (Van Zyl et al. 2007). The HDM-4 model's working mechanism is illustrated in equations 1 and 2. This model has proven to be highly sensitive in terms of its gravel material loss calibration factor (Uys 2011) that controls the entire shape of the model.

$$MLA = Kgl \cdot 3.65 \cdot \left(3.46 + 2.46 \cdot MMP \cdot RF \cdot 10^{-4} + KT \cdot AADT\right) \quad \textbf{(1)}$$

$$KT = Kkt \cdot Max\ \{0,\ [\ 0.022 + \frac{0.969 \cdot C}{57{,}000} + 3.42 \cdot MMP \cdot P075j \cdot 10^{-6} - 9.2 \cdot MMP \cdot PIj \cdot 10^{-6} - 1.01 \cdot MMP \cdot 10^{-4}]\} \quad \textbf{(2)}$$

where,
MLA = predicted annual gravel loss (mm)
Kgl = gravel material loss calibration factor
MMP = mean monthly precipitation (mm)
RF = average rise and fall of the road (m/km)
KT = traffic-induced material whip-off coefficient
AADT = annual average daily traffic
Kkt = traffic-induced material loss coefficient
C = average horizontal curvature of the road (deg/km)
P075j = amount of material passing through a 0.075 mm sieve
PIj = plasticity index of the subgrade material
Max = maximum positive value obtained

Technical Recommendation for Highways (TRH 20)

The South African *Technical Recommendation for Highways* (TRH 20) manual (Department of Transport 1990) was developed as a modification of the previous World Bank HDM-3 study that yielded similarly satisfactory results to the abovementioned HDM-4. The HDM-3 model's working mechanism is shown in equation 3. This model has proven to be highly sensitive to all the input parameters listed below (Uys 2011).

$$AGL = 3.65\,[ADT\,(0.059 + 0.0027N - 0.0006P26) - 0.367N - 0.0014PF + 0.0474P26] \qquad \textbf{(3)}$$

where,
AGL = annual gravel loss (mm)
ADT = average daily traffic
N = Weinert N-value
P26 = percentage of material passing a 26.5 mm sieve
PF = product of the plastic limit and percentage of material passing a 0.075mm sieve

Australian Road Research Board (ARRB)

The Australian Road Research Board (ARRB) has identified statistical errors and the presence of insignificant variables in the World Bank HDM-4 model and has thus adopted a gravel loss model based on field studies in Australia (Choummanivong and Martin 2004, Martin et al. 2013, Martin and Kadar 2015). The working mechanism for this model is presented in equation 4. This model also has proven to be highly sensitive to all the input parameters listed below (Uys 2011).

$$Gla = f\left[\frac{Ta^2}{Ta^2+50}\right][4.2 + 0.092Ta + 4.30R1^2 + 1.88Vc] \qquad \textbf{(4)}$$

where,
Gla = annual gravel loss (mm)
Ta = annual traffic in thousands in both directions
R1 = annual rainfall (m)
Vc = gradient (%) for uniform road length
f = constant for gravels

Similar gravel loss models have been studied and developed in other geographical locations as well, such as Brazil (Paige-Green and Visser 1991) and West Africa (Jones 1984). There has been limited work conducted on this topic in North America, especially in the US, though the gravel loss estimation in Visser (1981) was studied in Canada in 1990 (Turay 1990, Turay and Haas 1990).

Granular Roadway Management Systems (GRMS)

Several attempts have been made at the project, network, and strategic levels to assist local agencies in maintaining granular roadway systems. Project-level management makes decisions on specific roadway project construction, rehabilitation, and maintenance work, while network-level management assists local agencies in ranking and scheduling road work plans based on priorities, whereas strategic management is crucial, since it involves communication of road work decisions and plans with the general public.

Highway Development and Management (HDM-4) Model

The comprehensive HDM-4 model, developed by the World Bank, guides the technical and economic analysis of road projects, followed by roadway investment strategy suggestions. It requires the data attributes of roadway inventory, traffic volumes, and economic information as input variables. It consists of four sections, which are roadway deterioration, roadway user impacts, roadway maintenance work effects, and socioeconomic and environmental effects. Roadway deterioration is modeled in HDM-4 by estimating the impacts of traffic and weather loading followed by roadway drainage conditions. Roadway travel time, roadway accident, and vehicle operation costs are analyzed in a roadway user impact analysis. Impacts of roadway maintenance treatments and associated costs are estimated in a work effects module. Vehicle energy consumption and emissions are calculated to determine eco-environmental impacts. The HDM-4 model can be used to conduct section-by-section analysis for each road segment and recommend annual budget estimates. Users can simulate and analyze varying budget scenarios to identify the most efficient combination of roadway maintenance activities along with asset valuation that identifies the financial value for each road section. The finalized HDM-4 model allows users to take advantage of advanced features that are explained as follows:

- Sensitivity analysis: Identification of impacts for each input variable
- Multi-criteria analysis: Evaluation of the intrinsic value of roadway projects for the relevant communities
- Asset valuation: Assessment of roadway projects based on economic values and the development of project rankings based on funding priorities
- Budget scenario analysis: Evaluation of expected roadway performance under varying budget conditions

Road Economic Decision (RED) Model

The Road Economic Decision (RED) model (Archondo-Callao 1999a, 2000, 2004) was developed through case studies in Sub-Saharan African regions and is a modified version of the World Bank HDM-3 and HDM-4 models. In the RED model, a risk analysis module was included along with the other HDM-3 and HDM-4 features (Ellevset et al. 2007). The RED model is an extensive Microsoft Excel program that performs economic analysis for road projects, identification of investment strategy, comparison of maintenance activities, and sensitivity analysis. This model can also conduct economic analysis on roads section by section, along with providing an overall roadway network assessment.

Risk analysis in the RED model is conducted based on triangular distribution assumptions, whereas vehicle operating costs are only estimated in both the HDM-3 and HDM-4 models. Economic gains in the RED model are computed as a function of reduction in vehicle operating costs and through a safety analysis. Users have the option to include more benefits in their economic analysis. However, one of the limitations of this model is that it cannot provide predictions on roadway deterioration patterns; instead, it generates roadway performance estimates based on historical data collected for particular road sections.

Road Network Evaluation Tools (RONET)

Road Network Evaluation Tools (RONET) is a modified version of the RED model in which a deterioration modeling section is introduced (Archondo-Callao 2007a, 2009). This tool stands out in the sense that it can estimate the minimum annual budget requirements for a desired roadway reliability along with providing the regular features of the RED tool such as roadway economic evaluation, roadway vehicle operation cost, risk analysis, and roadway system performance evaluation.

RONET provides an extensive summary of the current roadway condition, the economic value of the existing roadway, and roadway performance indicators of interest for further assessments (Archondo-Callao 2007b). Roadway condition in RONET is assessed with a subjective estimate of roadway roughness (Archondo-Callao 1999b). Maintenance work is classified as three types, namely recurrent maintenance, periodic maintenance, and rehabilitations. This tool is designed for decision-makers, since it determines the net present values for road sections under varying budget conditions and identifies the most cost-effective strategies to achieve a minimum roadway reliability. In addition, it can pinpoint funding gaps in roadway maintenance budgets by comparing current versus required maintenance budgets.

Wyoming

The Wyoming guideline (Huntington and Ksaibati 2010) provides extensive description on granular roadway condition assessment, inventory development, cost and maintenance tracking, and condition-monitoring approaches. Its assessment section includes evaluation of the current policies in practice, an inventory chapter identifying the minimum data requirements for developing a granular roadway management system, along with detailed requirements that can generate a state-of-the-art data-driven roadway management system. In addition, its maintenance and cost tracking segment identifies all possible road work and its effects investigated through condition monitoring.

South Dakota

The South Dakota model provides guidance from a maintenance perspective. It contains gravel road construction, design, and maintenance manuals (Skorseth and Selim 2000, Skorseth et al. 2015). It also describes the significance of drainage and gravel (surface aggregate) materials quality. The South Dakota model explains roadway stabilization and dust control techniques, along with applications of emerging techniques for gravel road maintenance. It guides hand calculations of thickness design and aggregate quantity, along with an inspection checklist for motor graders. Based on daily truck traffic and a subjective assessment of subgrade soil condition, the minimum required gravel thickness suggested by this manual is shown in Table 2-1, and a typical form of the required motor grader operator checklist is illustrated in Table 2-2.

Table 2-1. Gravel thickness design chart

Daily truck traffic	Subjective soil condition	Minimum suggested gravel thickness (in.)
0–5	Low	6.5
	Medium	5.5
	High	4.5
5–10	Low	8.5
	Medium	7.0
	High	5.5
10–25	Low	11.5
	Medium	9.0
	High	7.0
25–50	Low	14.5
	Medium	11.5
	High	8.5

Table 2-2. A typical inspection checklist for motor grader operators

Attributes	Status			Vehicle No.
	OK	Repair	Follow-up	
Engine oil and filter				Location:
Air filter				Date:
Exhaust system				# of hours:
Parking brake				Performed by:

Australia

The Australian manual (Giumarra 2009) provides extensive guidelines for maintaining road networks, including in terms of maintenance, materials, design, and construction. It describes in detail roadway asset management and economic evaluation techniques, along with environmental and safety considerations. Key features of the Australian manual include infrastructure asset preservation prioritization; roadway classification; performance assessment, monitoring, and prediction; a roadway condition rating system; maintenance threshold identification; advanced asset valuation; and management approaches.

Canada

Current granular roadway management policies implemented in Canada were evaluated in Rashedi et al. (2017), which illustrated that local agencies perceive data collection on granular roadway conditions uneconomical for two reasons: (1) the apparent financial loss in investing time and resources on data collection and (2) the lack of standardized data management and analysis guidelines for granular roadways.

In Canada, municipalities are primarily responsible for maintaining granular roads, and Rashedi et al. (2017) found that a decision-making tool for system-wide granular roadway management is warranted for the majority of such municipalities. However, development of such a roadway asset management model appeared challenging due to data unavailability issues, and therefore, the authors provided guidelines for developing a smart roadway data inventory and data management approaches to be followed up by their recommended roadway performance prediction methodology along with their proposed budget scheduling techniques.

Limitations of Current Granular Roadway Management Systems

It is evident that the US (and Canada) lacks systematic data-driven granular roadway management system policies. The current state of technologies mainly involves data management and roadway condition monitoring techniques along with the adoption of efforts to catalogue historical roadway maintenance activities in the US, whereas developing countries in Africa as well as Australia have developed state-of-the-art data-driven roadway management systems specially designed for efficient granular roadway maintenance.

One of the most challenging issues in granular roadway management systems in the US is the institutional limitations. Granular roads are mainly managed by local agencies, which often do not possess the technical capabilities or the required resources in terms of funding and manpower to implement a state-of-the-art granular roadway management system. There has been a lack of development of system-level roadway condition assessment techniques. Local agencies cannot practically collect roadway inventory data for granular roads in section-by-section segments. Such challenges also invalidate the applicability of existing roadway deterioration models, since they cannot yield network-level roadway performance for upcoming years in the absence of current roadway segment-based information.

Federal transportation agencies conduct asset valuation prior to allocating funds for infrastructure. Economic valuation of a roadway network is primarily developed for paved roads and is conducted in terms of vehicle operating costs. Granular roadways account for a very limited number of vehicles; therefore, economic valuation approaches based on vehicle operating costs may not be suitable for granular roads. However, different roadway economic valuation strategies such as roadway sustainability indexing (Alam et al. 2018) can provide improved asset valuation of such roads, which may trigger additional funds for granular roads.

Components of a Data-Driven Granular Roads Asset Management System (GRAMS)

A data-driven roadway asset management system is essential for decision-makers to determine future financial risk, assess investment strategies and schedule a cost-effective maintenance, and determine a rehabilitation plan. An extensive asset management tool can assess financial trade-offs for long-term implications of various management decisions as well. Basic components of a data-driven roadway asset management system is illustrated in Figure 2-3.

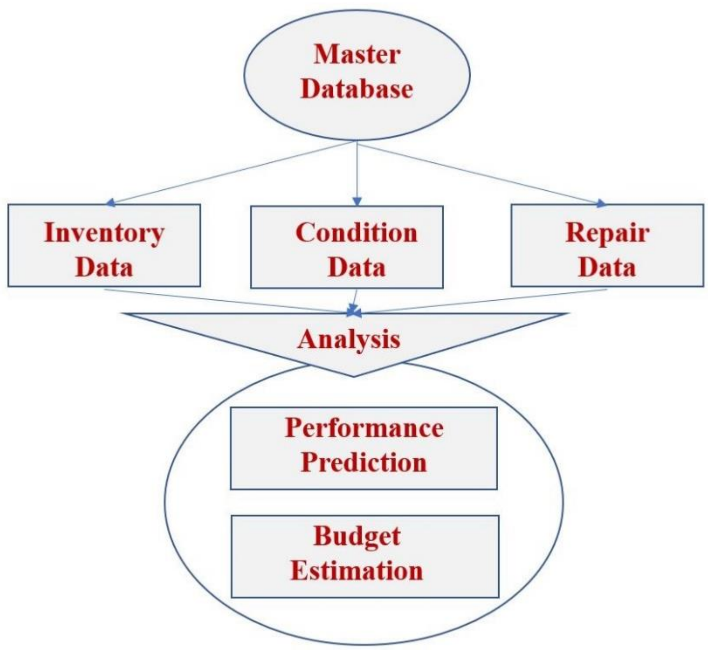


Figure 2-3. Components of granular roadway asset management system

Data Collection

A roadway system master database development requires continuous tracking of roadway inventory and condition and repair data as shown in Figure 2-3. For inventory development, data attributes of interest include but are not limited to roadway location, surface type, roadway length, unique identifier for sections, top width, terrain, traffic type, volume and speed limits, subgrade condition, whereas a repair data set includes information pertinent to blading, drainage maintenance, reshaping, stabilization, dust control, spot rocking, and major resurfacing. In Federal Highway Administration (FHWA) guidelines, potholes, washboarding, loose aggregates, and generation of dust are identified as the attributes of interest for investigating the condition of gravel roads (Pierce et al. 2013). Condition and magnitude monitoring ratings for the roadway, shown in Table 2-3, are based on data attributes such as crown and drainage and were developed in previous studies.

Table 2-3. Granular roadway condition rating

Rating	Remarks
5	New construction, excellent crown and drainage, no maintenance needed
4	Good crown and drainage, routine maintenance required
3	Regrading, minor maintenance, spot rocking needed
2	Additional aggregate layer and major drainage improvement required
1	Complete reconstruction needed

Source: Walker 2002

The condition rating changes from 5 to 1, indicating the gradual decline of a newly constructed granular roadway (rating 5) to the total failure of the roadway (rating 1). Roadway condition data can be collected by visual inspection, automated condition monitoring devices such as application of unmanned aerial vehicles, light detection and ranging (LIDAR), photographs, and roadway thickness measurements.

Data Management

Unique roadway location identification is considered one of the major challenges in roadway data management. Location information management systems for roadway maintenance purposes are available in FHWA guidelines as shown in Table 2-4.

Table 2-4. Roadway location management system

Location method	Remarks
Route milepost system	Distance is measured from a known point to a referenced location
Route reference post system	Signs posted in the field are used to indicate known location Advantageous over route milepost method
Link node system	Physical features (i.e., intersections) are given unique node number and link is the length between nodes
Route street reference system	Local street name is used to identify the road segment
Geographic coordinates system	Lat-long or Cartesian coordinate system is followed

Source: Smith et al. 2001

Recognized roadway data management techniques are classified in three categories as shown in Figure 2-4.

Figure 2-4. Roadway data management system

A manual data management system, regarded as level 1, where file cabinets are used to store paper copies of the data. In the case of a granular roads maintenance program, information includes road condition or rating number for performance data and rock tickets or load sheets indicating the date and amount of aggregate applied in a location along with unit price for hauling, material, and labor costs, etc. In level 2, all the manually collected performance, operation, and maintenance information are stored in spreadsheets. Finally, the highest quality data management, level 3, can be achieved through a geographic information system (such as ArcGIS), where all the spreadsheet information is stored in a dynamic map.

Data Analysis

Limited works has been done in the US to develop a practical data-driven model to predict granular roadway performance and estimate annual budgets. Existing mathematical models developed from international efforts require extensive site-specific data collection and monitoring of the roadway system as discussed in earlier in this chapter, and therefore, the application of such models to predict roadway performance is limited. In the US, a practical granular roadway management system was recommended in Huntington and Ksaibati (2010). As shown in Table 2-5, local agencies are required to collect roadway data via segment-by-segment maintenance activities.

Table 2-5. Roadway maintenance information tracking system

Date	Maintenance tasks	Drainage	Blading	Dust control	Minor repair	Regravel
01/19	Drainage	X				
03/19	Blading		X	X		
05/19	Dust control				X	
06/19	Minor repair		X		X	
07/19	Regravel		X			X

Such information tracking activities will assist the local agencies in identifying the problematic sections (i.e., where frequent maintenance is warranted). As shown in Figure 2-5, historical practice-based approaches should be used to schedule a roadway maintenance program.

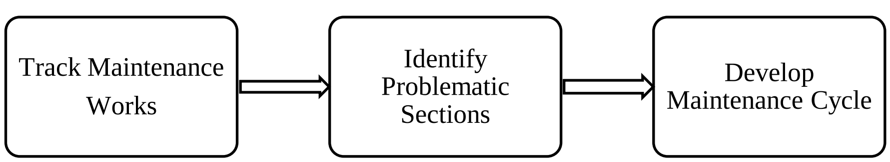


Figure 2-5. Roadway maintenance decision-making system

However, such policies are primarily reactive, since no mathematical modeling of performance predictions are applied. In addition, local agencies are required to invest a significant amount of resources to track and monitor roadway systems in a section-by-section basis, and therefore, this historical practice-based approach is not practically implementable.

CHAPTER 3. STATE OF GRAMS IN IOWA

The objective of this chapter is to assess the current state of granular roadway management practices in Iowa. A web survey was conducted with Iowa county engineers to collect information on the current state of granular roadway management practices. The current state-of-practice in Iowa is compared to the state-of-the-art roadway management approaches explained in Chapter 2. Complete survey results are available in Appendix A.

Methodology

An online survey was distributed to Iowa counties in February 2018 to collect information on operation and maintenance practices for granular roads. The target population was county engineers because of their years of experience in granular road management. The survey questionnaire was prepared in consultation with subject matter experts, and based on the complexity, the questions were designed as closed-form as well as open-ended. Survey questions ranged from understanding the granular roadway maintenance practices from a practical point of view (i.e., annual requirement of replacement gravel, rock and aggregate sources, factors influencing maintenance decisions, and budget and cost information) to the current documentation and management practices (i.e., types and extents of current roadway inventory databases and software and technologies used). Similar surveys were conducted in previous studies to understand current granular roadway management practices (Huntington and Ksaibati 2010).

Survey Results

Of Iowa's 99 counties, 39 responded to this survey, yielding a response rate of 39%. The geographic distribution of survey respondents is shown in Figure 3-1.

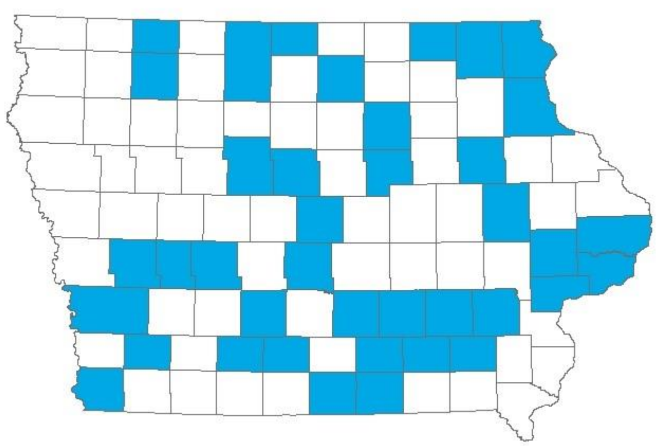


Figure 3-1. Geographic distribution of survey respondents

A checklist shown in Table 3-1 was prepared to develop a ranking based on granular roadway management policies of local agencies. Data collection attributes were given an equal weight. In data processing, relative weighting was given if any digital database system was introduced. For data analyses, additional weighting was selected as shown in Table 3-1.

Table 3-1. Granular roads management policy assessment checklist

<table>
<tr><td rowspan="11">Data collection</td><td rowspan="4">Performance data</td><td>Potholes</td></tr>
<tr><td>Washboarding</td></tr>
<tr><td>Dust</td></tr>
<tr><td>Loose aggregate</td></tr>
<tr><td rowspan="7">Operation and maintenance data</td><td>Aggregate quantity</td></tr>
<tr><td>Aggregate location</td></tr>
<tr><td>Pits/Quarries</td></tr>
<tr><td>Material cost</td></tr>
<tr><td>Hauling cost</td></tr>
<tr><td>Traffic variation</td></tr>
<tr><td>Aggregate quality</td></tr>
<tr><td rowspan="3">Data processing</td><td colspan="2">Manual management</td></tr>
<tr><td colspan="2">Spreadsheet database (25% weight)</td></tr>
<tr><td colspan="2">ArcGIS database (50% weight)</td></tr>
<tr><td rowspan="2">Data analysis</td><td colspan="2">Performance prediction and pavement ranking (100% weight)</td></tr>
<tr><td colspan="2">Optimization and budget scheduling (100% weight)</td></tr>
</table>

None of the survey participants scored any points in the performance data collection and data analysis sections. Equation 5 was used to develop a ranking of counties based on their granular roadway network data management practices.

$$P_f = \frac{\sum w_i p_i}{n} \quad \textbf{(5)}$$

where,
P_f = final point scored by the local agencies
w_i = relative weight of the i-th attribute
p_i = associated point scored by the county for i-th attribute
n = total number of attributes

Based on this methodology, the top five local agencies were identified in terms of granular roadway data management practices as shown in Table 3-2.

Table 3-2. Agency ranking based on granular roadway data management practices

County	Relative score (P_f)
Scott	0.97
Butler	0.87
Marion	0.85
Washington	0.80
Montgomery	0.77

The top three counties have developed a comprehensive historical granular roadway management database with all three levels as shown in Figure 2-4. The remaining two counties adopted a moderate historical granular roadway management database with levels 1 and 2 as shown in Figure 2-4. In addition, all five counties collect aggregate material quality information including gradation and annual cost information (e.g., material, labor, and blading costs).

Key findings from survey responses are summarized throughout the remainder of this section. The full survey questionnaire and responses are provided in Appendix A.

- Local agencies tend to follow experience-based approaches to assess roadway condition and aggregate (rock) quality as shown in Table 3-3.

Table 3-3. Roadway condition and aggregate quality assessment policy

Assessment attribute	Policy	Responses, % (No.)*
Roadway condition	No form of structured assessment system/Graders' experience	53% (21)
	Partial dependence on graders' experience	97% (38)
	Measuring roadway thickness, crown, etc.	12% (5)
Aggregate quality	Visual inspection/Previous experience	35% (14)
	Partial reliance on visual inspection/Previous experience	89% (35)
	Ledges in quarries	23% (9)

*Number and percentage based on the 39 counties responding.

- Local agencies keep historical roadway operation and maintenance records with the primary focus of tracking the amount and location of aggregate (rock) application as well as aggregate (rock) purchase expense records as shown in Table 3-4.

Table 3-4. Roadway operation and maintenance data collection practices

Attributes collected by local agencies	Responses
Quantity of aggregates	82%
Location of aggregates	82%
Material cost	97%
Hauling cost	47%
Pits and quarries	75%
Property of materials	44%
Seasonal traffic	12%

Data storage methods vary from manual load sheets/ aggregate (rock) tickets and paper maps to digital copies of Excel, AutoCAD, and ArcGIS files.

- Ton per mile (TPM) aggregate (rock) requirements for maintenance varies among counties with an average 292 TPM with a standard deviation of 185 TPM. Geographic distribution for TPM requirements is shown in Figure 3-2.

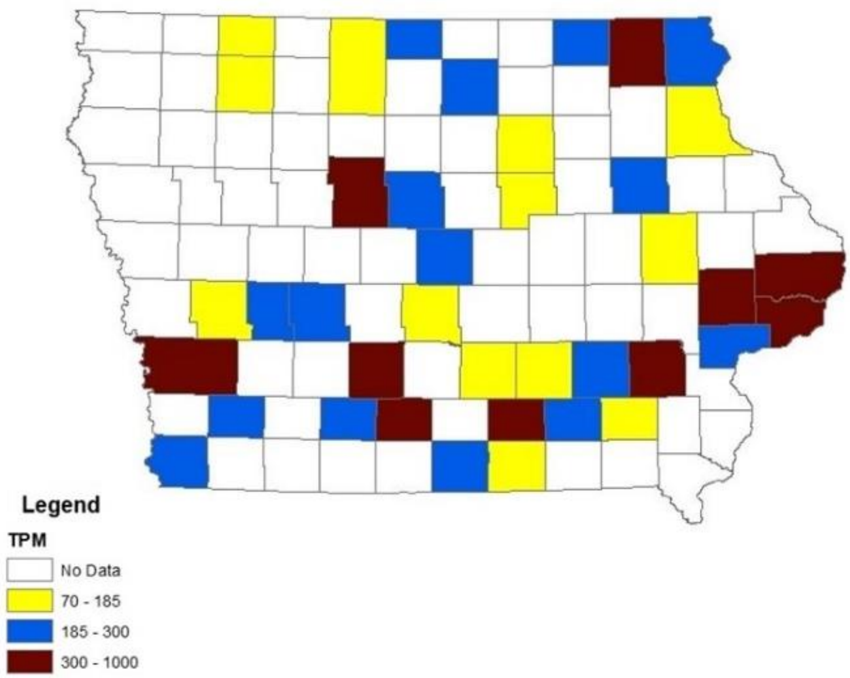


Figure 3-2. Geographic distribution of Iowa counties based on TPM requirements

TPM requirements vary from 70 for Clay County in northern Iowa to 1,000 for Scott County in eastern Iowa. A total of 36 out of 39 (92%) counties reported 100 to 500 TPM requirements with an average of 270 and standard deviation of 120 TPM, which indicates the TPM application rate of the remaining 3 counties can be considered as outliers.

- Unit price for aggregate ($/ton) varies among local agencies with an average of $9.37/ton and standard deviation of $3.15/ton. The material cost ranges from $2.3/ton in Clay County to $18/ton in Montgomery County in southwest Iowa. The geographic material cost distribution is shown in Figure 3-3.

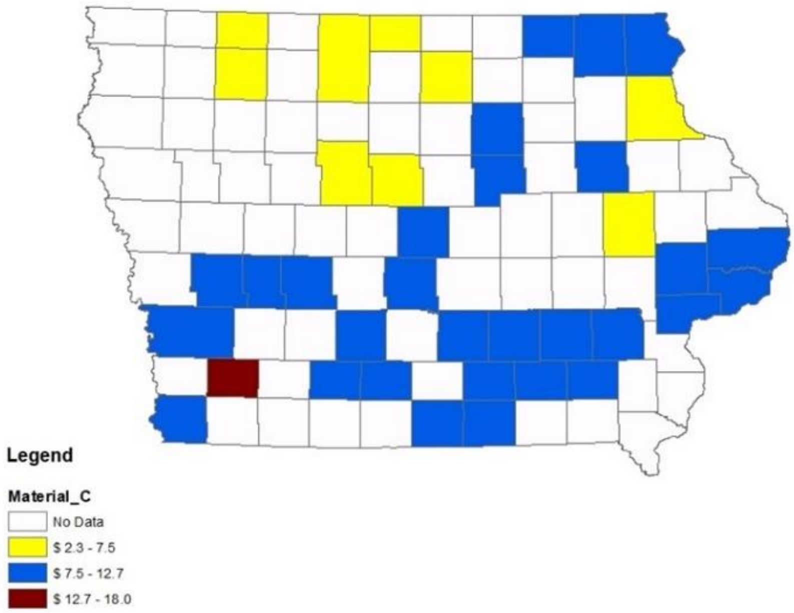


Figure 3-3. Geographic distribution of Iowa counties based on material unit price

- Local agencies place a higher emphasis on cost compared to quality of aggregate (rock) in their decision-making process for roadway management as shown in Table 3-5.

Table 3-5. Factors influencing decisions for roadway maintenance

Factors	Responses
Material cost	84%
Hauling cost	74%
Material quality	54%

Conclusions

After reviewing the existing granular road management policies of Iowa's local agencies, the following recommendations are suggested to address the barriers in implementing a consistent granular roadway management program:

- Local agencies should consider adoption of subjective opinion-based policies using simple index values to assess material quality and roadway condition. Grader operators can score their district roadway performance and applied aggregate (rock) quality on an annual basis.

Such a policy can provide a foundation to develop a data-driven granular roadway management system.

- Local geographic variables such as aggregate (rock) and subgrade quality are likely the cause for the significantly different TPM requirements of Clay (70) and Scott (1,000) counties. In the case of material cost, a specific geographic pattern was detectable from northern to southern Iowa, which corresponded to material availability from north to south. However, 92% of survey responses showed a comparatively narrow range of TPM requirements irrespective of geographic location, which could be caused by unique local variables such as different reliability and available aggregate (rock) budget for each county. To address unique county-specific factors, roadway management policies should be developed at the agency level.

- Local agencies should follow the comprehensive data management approach as was shown in Figure 2-4. Based on the survey responses, it was revealed that Scott County had adopted such comprehensive data management strategies. Similar to Scott County, for each load of resurfacing, each local agency should prepare an aggregate (rock) ticket/load sheet that includes the aggregate (rock) amount, location, and date of application for each section. The data from those tickets/load sheets should be digitalized in two stages, by entering it into a spreadsheet and then entering it into geographic mapping software, such as ArcGIS.

CHAPTER 4. GRAMS METHODOLOGY

The data collection process and analysis methodology for the development of the GRAMS tool are discussed in this chapter, including the results and discussion. Responses gathered through both survey questionnaires are presented in Appendix A and B, the surface condition rating report used in the surveys is presented in Appendix C and a summary of historical data are presented in Appendix D.

Background

Based on the literature, the most challenging tasks for local agencies in granular roadway management are as follows:

- Inadequate methodologies are available to manage granular roadways
- Inadequate resources are available to collect granular roadway data

The desired outcomes of granular roadway management systems are as follows:

- Help decision-makers and officials in making engineering roadway investment decisions
- Help roadway engineers in making efficient rehabilitation and maintenance decisions and maximize the granular roadway network performance

The key points identified from the state-of-practice in granular roadway management in Iowa are as follows:

- Local agencies collect a significant amount of granular roadway operations data, especially in terms of annual budgets.
- Local agencies track roadway maintenance data, particularly the amount and location of aggregate (rock) materials used.
- There has not been enough data for roadway performance. As a result, current practices on roadway maintenance are primarily reactive/ad hoc. Local agencies typically perform maintenance activities when it is warranted instead of conducting proactive maintenance, which involves future roadway performance prediction and maintenance scheduling.
- Due to the ad-hoc maintenance practices, the roadway maintenance data currently collected by local agencies may not satisfy the data quality requirements to develop a data-driven roadway management system.
- Local agencies generally have neither the financial solvency to develop full-scale roadway inventory for a granular roadway management master database nor the manpower to conduct regular roadway condition monitoring.

This research put an emphasis on solving the following challenges:

- Current literature on granular roadway management policies has mostly focused on

developing an extensive inventory, followed by regular roadway condition management in a segment-by-segment approach
- Due to inadequate roadway inventory and condition information, the effectiveness of existing granular roadway management guidelines is questionable from a practical point of view
- Existing gravel loss prediction models, which were developed through extensive field studies, often require site-specific roadway data to put into practice

After assessing such challenges, the research team decided that development of a mathematical granular roadway performance prediction model that could use data that is readily available to local agencies would be the foundation for a data-driven granular roadway asset management system.

This tool can play a vital role in making proactive budgetary decisions for roadway maintenance. The objective is to develop a simplified and computationally less extensive mathematical model that can overcome the obstacles associated with existing granular roadway maintenance systems.

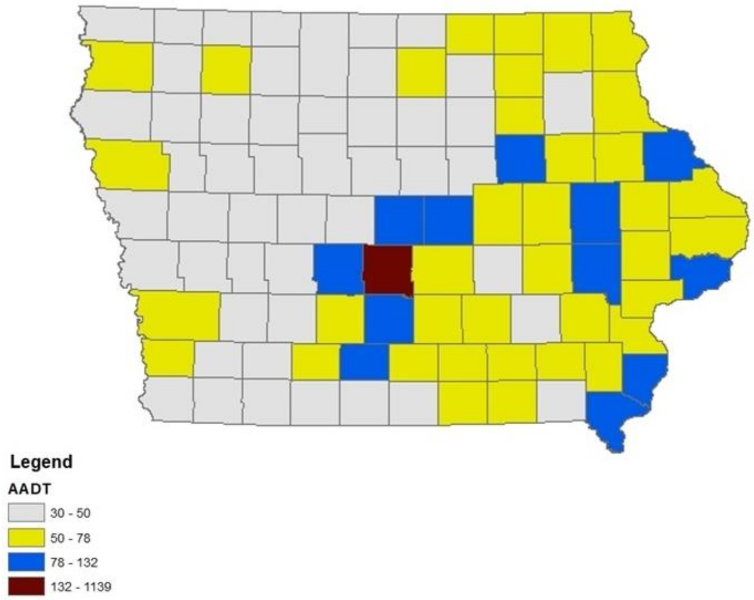
Data Collection

Influential Factors in Roadway Deterioration

Truck traffic, quality of aggregate, subgrade soil properties, and precipitation were identified as the critical influential factors on granular roadway deterioration through extensive literature reviews and consultations with experienced professionals in this field. These four critical influential factors can be further broken down into two categories: internal factors or external factors. Subgrade soil properties and aggregate quality are classified as internal factors. Annual traffic and precipitation are external factors because these factors are environmental-related, of which local agencies have no control.

Annual Average Daily Traffic (AADT)

Annual average daily traffic (AADT) data were extracted from the Iowa Department of Transportation (DOT) Geographic Information Management System cloud database. AADT data from 2016 were the latest available traffic data in the DOT database during the development of the GRAMS tool. By applying an annual growth factor, this traffic data can be projected for future years. A traffic-level map of Iowa is shown in Figure 4-1.



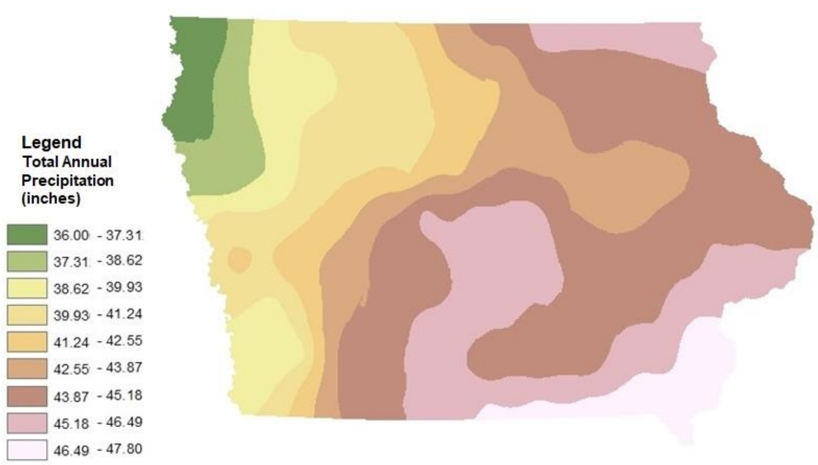
Source: https://cloud.iowadot.gov/GIS/data/GIMS/statewide/

Figure 4-1. Iowa AADT by county

Except for Polk County (AADT: 1,139), most Iowa counties experience similar levels of annual traffic (AADT: 30–132).

Annual Precipitation

Annual precipitation data for Iowa counties were extracted from the Long-Term Pavement Performance (LTPP) database administered by the FHWA (2016). To accurately consider the effects of seasonal variations in precipitation, 10 years of precipitation data, from 2007 through 2016, were used. Average annual precipitation was then calculated for each Iowa county as shown in Figure 4-2.



FHWA 2016

Figure 4-2. Iowa precipitation

Figure 4-2 shows the northwest region of Iowa receives the greatest amount of precipitation annually (from 46.49–47.80 in.), whereas the southeast region of Iowa receives the least amount of precipitation annually (from 36–37.31 in.), which is approximately 10 in. less than the northwest region.

Subgrade Soil Quality

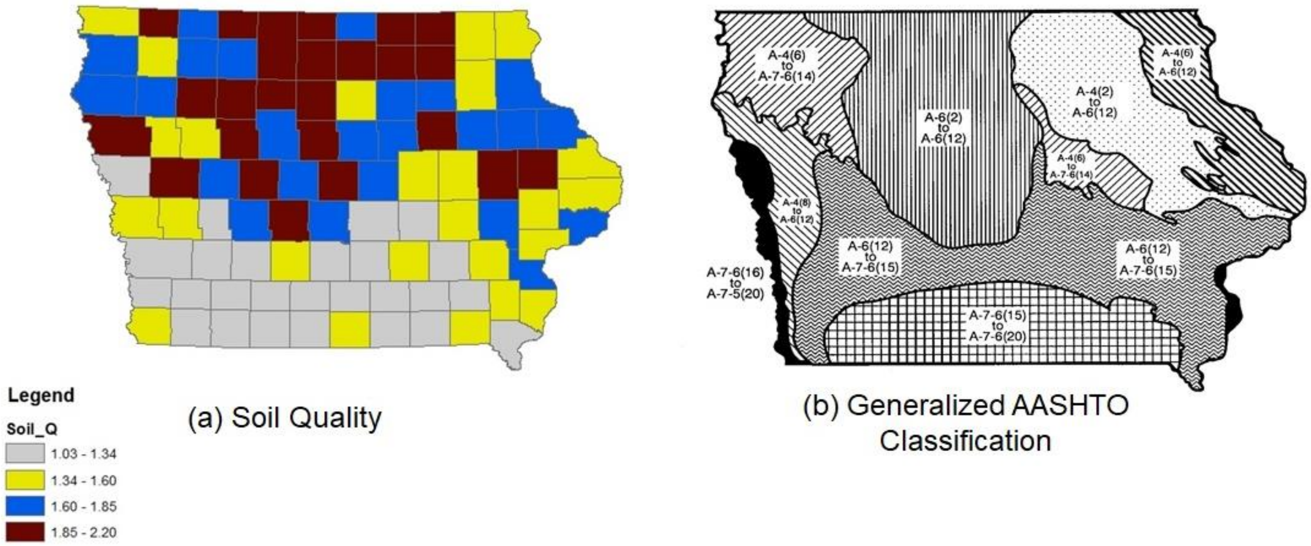
A soil score rating was developed specifically for Iowa counties based on the Web Soil Survey (WSS) database. Under this rating system, each Iowa county is assigned a score based on the criteria specified in Table 4-1.

Table 4-1. Classification of Iowa subgrade soils

Subgrade soil properties	Relative score
PI > 10, high shrink-swell potential, GWT < 1 ft, slope > 25%	1
>35% passing sieve #200, PI < 10, moderate shrink-swell potential, slope 15–25%, GWT between 1–3 ft	2
Low shrink-swell potential, slopes 15% or less, water table more than 3 ft, significant gravel, sand, few stones	3

PI=plasticity index, GWT=ground water table

Iowa subgrade soils were scored within a range from 1 to 3, based on in situ characteristics and soil properties such as plasticity index, gradation, shrink-swell potential of soil, as well as depth of ground water table and slope. In the soil quality scores, 1 corresponds to below average subgrade soils frequently observed in southern parts of Iowa, whereas 3 corresponds to above average subgrade soils scattered in northern parts of Iowa. To ensure the validity of this approach, Figure 4-3 compares the American Association of State Highway and Transportation Officials (AASHTO) soil classification with the developed soil score for Iowa soils.



Source: https://www.nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId=IA

Figure 4-3. Iowa soil quality and generalized AASHTO classification

The AASHTO classifications of A-6 and A-7 subgrade soils correspond to the weakest in terms of soil strength and stiffness and are similar to subgrades with a relative score of 1 based on the WSS database. In contrast, the AASHTO classifications of A-1 and A-2 soils exhibit higher strength properties corresponding to the WSS soil relative score of 3. Both figure 4-3a and b show similar patterns of Iowa subgrade soils, in that the southern parts of the state consist of below average soils (A-6, A-7 or score 1), whereas the northern parts correspond to average quality soils (i.e., A-4 or score 2).

Zone Map of Iowa

Each county of Iowa was classified into one of four zones based on its relative roadway deterioration impact in terms of AADT, average annual precipitation, and subgrade soil quality. A zone standard normal was calculated for the AADT, average annual precipitation, and subgrade soil quality for each county using equation 6.

$$Z_{stdn} = \frac{SQ_{stdn} - AADT_{stdn} - PRCP_{stdn}}{3} \quad \textbf{(6)}$$

where, Z_{stdn} is the zone standard normal for a county, and SQ_{stdn}, $AADT_{stdn}$, and $PRCP_{stdn}$ are the standard normal of subgrade soil quality, AADT, and annual precipitation, respectively, for a county. Zones were then defined based on each quartile point of the zone standard normal. Due to exceptional annual traffic, Polk County’s AADT was not considered as part of its zone’s standard normal calculation.

The zone map of Iowa is shown in Figure 4-4.

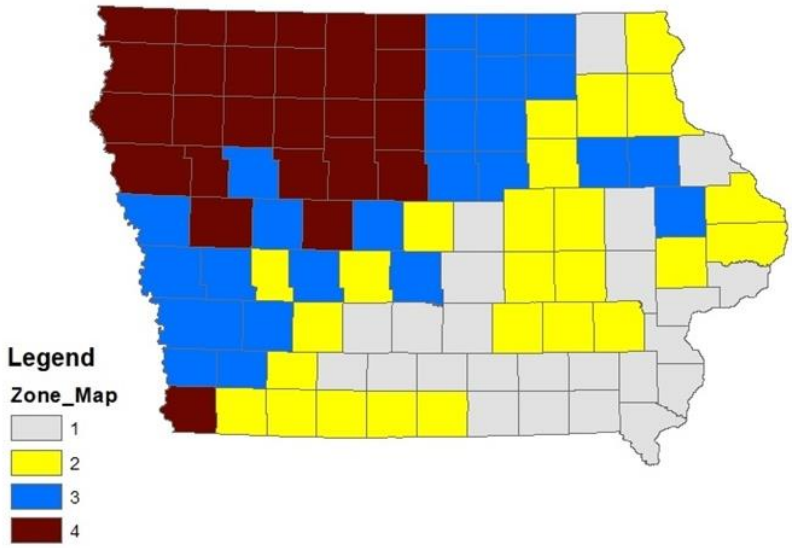


Figure 4-4. Iowa zones by county

Zone 1 shows counties with below average soil quality along with above average AADT and annual precipitation; Zone 2 shows counties with slightly below average soil quality along with slightly above average AADT and annual precipitation; Zone 3 shows counties with slightly above average soil quality along with slightly below average AADT and annual precipitation; and Zone 4 denotes the counties with above average soil quality along with below average AADT and annual precipitation.

Aggregate (Rock) Material Quality

Two indicators, the Los Angeles (LA) abrasion and percentage of materials finer than a #200 sieve (particle size < 0.075 mm), were chosen to characterize the aggregate quality. LA abrasion and fines content of aggregate materials were collected from 11 and 25 Iowa counties, respectively. In order to make inferences for the remainder of Iowa counties, zone averages of such material properties were considered. It was assumed that counties within the same zones experience similar level of annual gravel loss, and therefore, their AADT, annual precipitation, soil quality, and aggregate quality can be assumed to be similar. Then, each zone classification (1 through 4) in Figure 4-4 was correlated with these two indicators as shown in Table 4-2.

Table 4-2. Aggregate (rock) material qualities of Iowa zones

Zone	Los Angeles abrasion (%)	Percentage finer than #200 sieve
1	38.50	6.65
2	40.21	8.25
3	31.57	7.88
4	33.33	8.67

Data Collection Summary

A summary of characteristics of Iowa zones is illustrated in Figure 4-5 and Table 4-3, which confirmed the underlying assumptions of zone development (i.e., counties within the same zone exhibit similar ranges of AADT, precipitation, and soil quality).

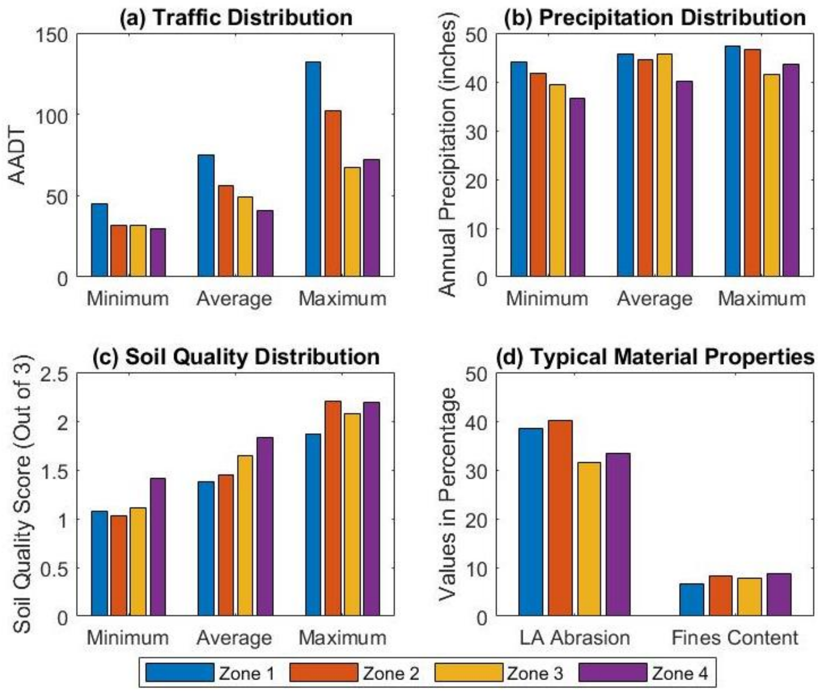


Figure 4-5. Characteristics of Iowa zones: (a) daily traffic distribution, (b) annual precipitation distribution, (c) soil quality distribution, and (d) typical material properties

Table 4-3. Summary of data used to develop Iowa zones

	AADT			Annual precipitation (in.)			Soil quality		
Zone	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**
1	45	75	132	43.99	45.70	47.41	1.08	1.38	1.87
2	32	56	102	41.82	44.60	46.73	1.03	1.45	2.20
3	32	49	67	39.40	45.64	41.41	1.11	1.65	2.07
4	30	41	72	36.56	40.12	43.58	1.41	1.83	2.19

It is evident that AADT decreases from Iowa zone 1 (AADT 45–132) to zone 4 (AADT 30–72), annual precipitation decreases from Iowa zone 1 (44–47 in.) to zone 4 (37–40 in.), and soil quality score increases from Iowa zone 1 (score 1.08–1.87) to zone 4 (score 1.41–2.19). Due to inadequate information on aggregate material qualities, average values were calculated as shown in Table 4-2 instead of developing a range of values. The full data sets on AADT, annual precipitation, soil quality score, and aggregate quality (LA abrasion and percentage of materials finer than a #200 sieve – only available for selected counties) of Iowa counties are presented in Appendix D.

Roadway Deterioration

TR 704 – Performance-Based Evaluation of Cost-Effective Aggregate Options

The performance of a granular road is strongly dependent on the material quality, operating conditions (traffic volume and loading), and climatic conditions. Granular roadway performance data were collected from test sections built for the *TR-704 Performance-Based Evaluation of Cost-Effective Aggregate Options for Granular Roadways* project. The project performance data were collected, since they include performance data for test sections built with aggregate materials sourced from various quarries around Iowa. In this project, seven different field test sections were built in Van Wert, Iowa (Decatur County), which provided a decent amount of data to model the performance of granular roadways that were built with different quality aggregates. The test sections were as follows:

- Section 1: High-strength Class A limestone aggregate
- Section 2: High-strength Class A dolomite aggregate
- Section 3: Low-strength Class A limestone aggregate
- Section 4: A mixture of low-strength Class A limestone aggregate and high-strength clean limestone aggregate
- Section 5: A mixture of low-strength Class A limestone aggregate and low-strength clean limestone aggregate
- Section 6: A mixture of low-strength Class A limestone aggregate and high-strength clean dolomite aggregate
- Section 7: A mixture of low-strength Class A limestone aggregate and high-strength clean crushed gravel

Field performance tests included dynamic cone penetrometer (DCP), light weight deflectometer (LWD), falling weight deflectometer (FWD), multichannel analysis of surface waves (MASW), dustometer, and density tests were conducted. Extensive laboratory tests were also performed, and performance data were collected periodically. The gravel loss deterioration of this roadway section was tracked for a period of 21 months.

High-quality aggregate (rock) materials are typically not available for granular roadways maintenance work, and therefore, inclusion of aggregate quality information in annual gravel loss prediction was thought not to be practical. In this current study, *TR-729 Development of Granular Roadway Asset Management System*, the roadway test Section 3 from the *TR-704 Performance-Based Evaluation of Cost-Effective Aggregate Options for Granular Roadways* project was used to calibrate and validate the developed gravel loss model. Section 3 was constructed with locally available Bethany Falls Limestone (BFL) Class A types of limestone aggregates. A typical profile and cross section of the roadway are shown in Figures 4-6a and b, respectively.

Figure 4-6. Roadway test site (a) top view and (b) cross section

The properties of the aggregate (rock) materials used for construction are illustrated in Table 4-4.

Table 4-4. Properties of aggregate (rock) material used

Fines content (%)	LA abrasion (%)	Gravel-to-sand ratio	Breakage potential	CBR from DCP (%)	Elastic modulus (N/mm^2) from MASW		Density (kN/m^3)	
					Large hammer	Small hammer	Dry	Wet
15.08	41%	2.53	1.63	85.46	860.17	600.10	20.58	19.32

The test section was a 500 ft long and 30 ft wide granular road. It was constructed to achieve a thickness of 4 in. with locally available aggregate materials in Decatur County, Iowa. The gravel loss deterioration and roadway maintenance activities of this roadway section were tracked for a period of 21 months. The developed annual gravel loss prediction model was validated with gravel loss observed in this test section.

Web Survey October 2018

Developing a robust mathematical model based on roadway deterioration data from one roadway section was challenging, and therefore, a web survey was distributed to Iowa county engineers and motor grader operators in October 2018. In this survey, experience-based subjective opinions were collected to better understand the deterioration processes of granular roads. This information was used to develop a mathematical model to predict annual material requirements.

The questionnaire consisted of an online survey and a surface condition rating report. The purpose of this survey was two-fold: (1) to construct an empirical database pertaining to granular roadway condition and deterioration rate for each county and (2) to understand the relationship between granular roadway condition and maintenance activities performed by local agencies. The target audience of this web survey was county engineers and motor grader operators due to their extensive knowledge and experience in the management and/or maintenance of granular roads. Subject matter experts were consulted to develop the survey. Details on this survey, including the responses from all participating counties, are presented in Appendix A and B.

Twenty counties in Iowa participated in this second (October 2018) survey:

- Allamakee
- Clay
- Clayton
- Clinton
- Dickinson
- Guthrie
- Hamilton
- Howard
- Jefferson
- Keokuk
- Kossuth
- Marion
- Monroe
- Montgomery
- Muscatine
- Polk
- Scott
- Story
- Union
- Washington

The first three questions of the survey were designed to collect preliminary information on the granular roadways in each county on a system level. Some of these findings are illustrated in Figures 4-7 through 4-9.

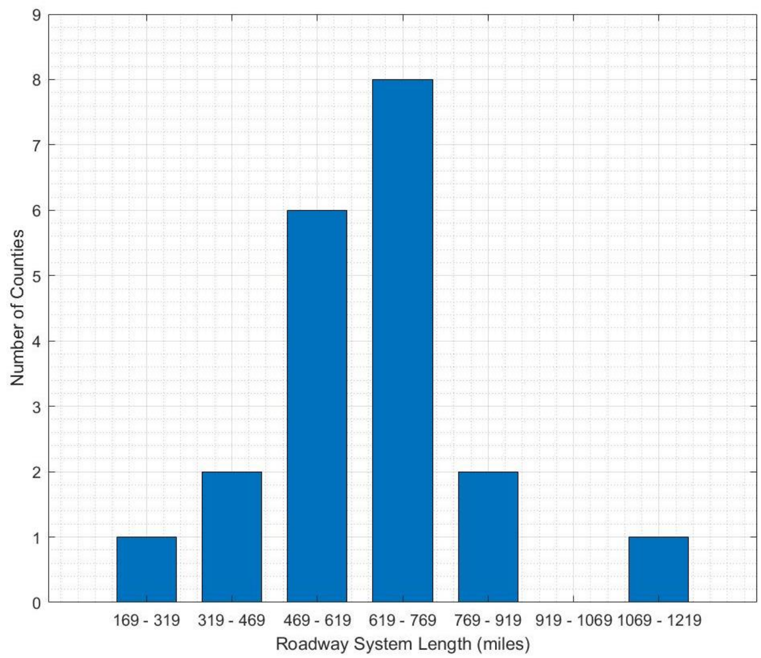


Figure 4-7. Granular roadway length by number of Iowa counties

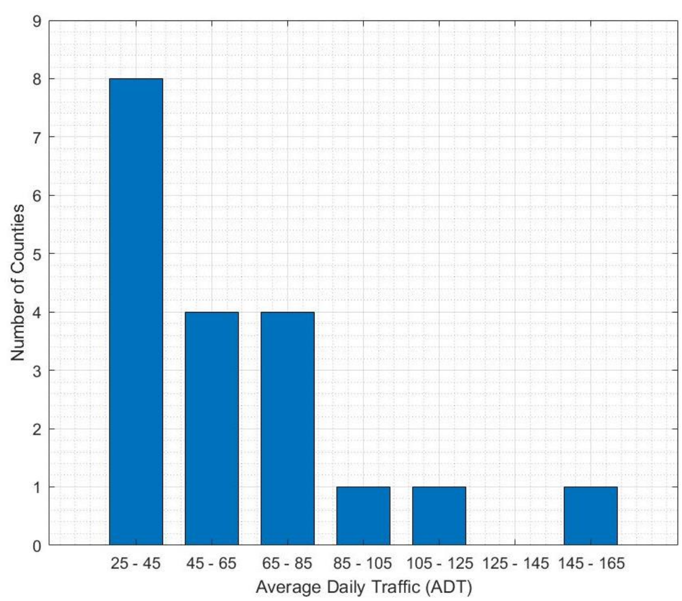


Figure 4-8. Average daily traffic on granular roadways by number of Iowa counties

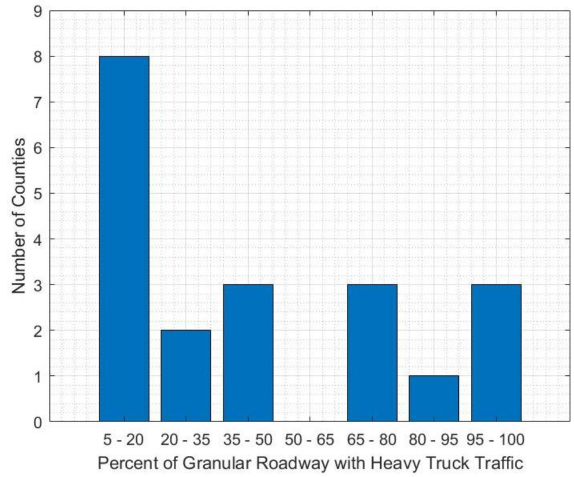


Figure 4-9. Percentage of granular roads with heavy truck traffic by number of Iowa counties

Figure 4-7 shows the total length of granular roadway networks for most of the counties (70%) to be between 469 mi and 769 mi. The average width of the granular roadways across the 20 counties was determined to be 26 ft. Figure 4-8 shows the average daily traffic on granular roads in 80% of the counties participating in the survey is equal to or less than 85 vehicles per day, with 40% of the counties reporting equal to or less than 45 vehicles per day. Figure 4-9 shows that 65% of the counties reported that 50% or less of the traffic load contained heavy trucks, while 35% of the counties reported that this number was equal to or greater than 65%.

Figure 4-10 shows the responses from both county engineers and motor grader operators agreed on the seasonal trends of truck traffic on granular roads (i.e., it remains largely unchanged from January through August each year and increases from September through December each year).

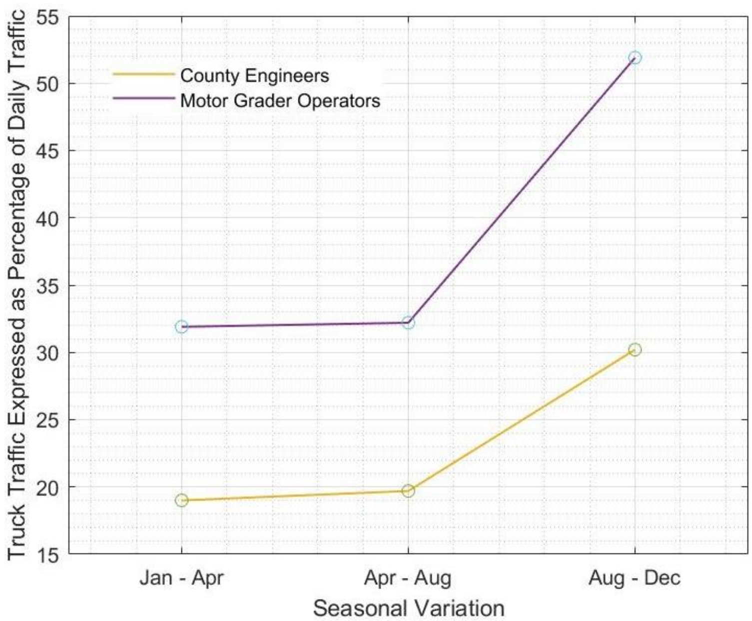


Figure 4-10. Seasonal variation of truck traffic (with respect to daily traffic)

The next section of the survey aimed to collect empirical information about the initial condition and deterioration rate of granular roadways from each county. To ensure a uniform understanding of granular road condition among all survey participants, a "definition of terms for overall surface condition" table was presented to each respondent (Table 4-6).

Table 4-6. Definition of terms for overall surface condition

Surface condition	Description
Excellent	• Newly constructed/maintained road • Excellent crown and drainage • No maintenance required
Good	• Good crown and drainage • Routine maintenance required
Fair	• Roadway shows deteriorating effects from traffic • Regrading, spot rocking, minor ditch maintenance required
Poor	• Road needs resurfacing • Major drainage maintenance works required
Unacceptable	• Complete rebuilding required

There is a total of five categories to describe the condition of granular roadway, ranging from excellent to unacceptable.

Figure 4-11 shows that 43% of the respondents reported that the thickness of a granular road section should be at minimum 4 in. to be classified as in excellent condition.

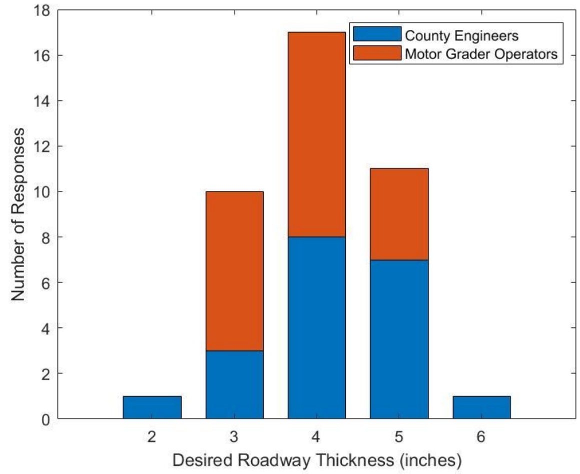


Figure 4-11. Desired minimum thickness of granular roads for excellent condition

Figure 4-12 indicates that, on average, the percentage of a granular roadway that is expected to be unacceptable increases in a fairly linear manner if no maintenance activities were conducted for a period of seven years.

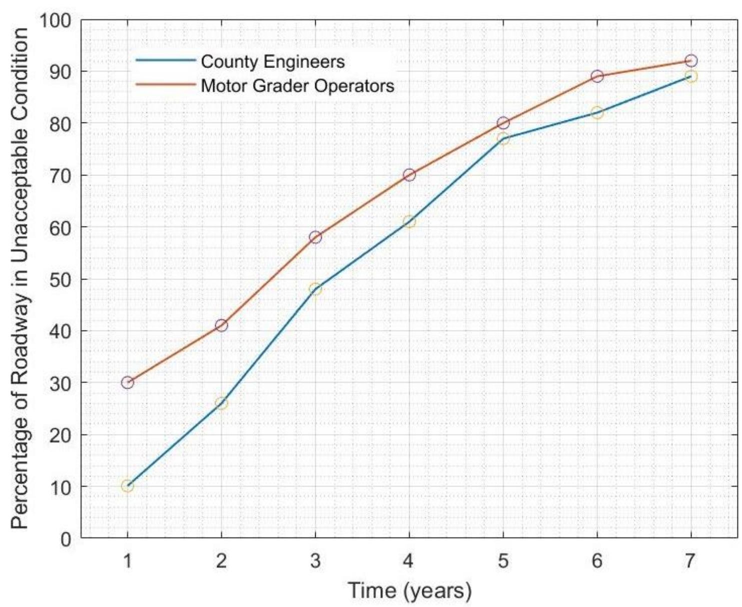


Figure 4-12. Percentage of granular roadway expected to be unacceptable if no maintenance activities are performed

Figure 4-12 also shows that approximately 50% of the granular roadways will be unacceptable (i.e., complete reconstruction required) after three years of zero-maintenance, given that the initial condition of the roadway is excellent. Figure 4-13 shows that the majority (71%) of the respondents (both county engineers and motor grader operators) reported 2 in. as the minimum thickness of gravel before resurfacing must be performed.

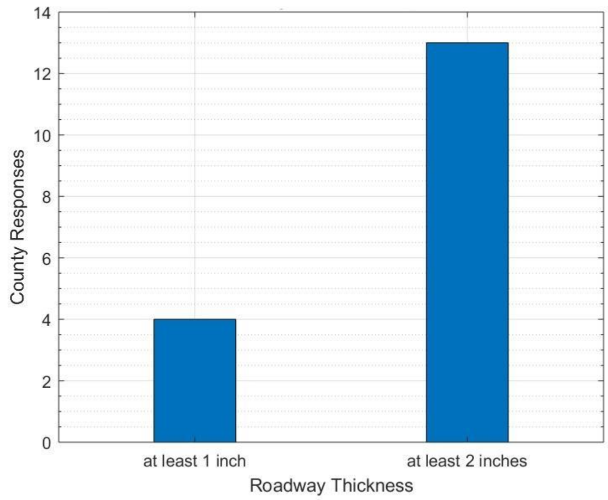


Figure 4-13. Minimum roadway thickness to trigger maintenance activities

To further understand the surface condition of granular roads, the research team identified seven distress characteristics commonly associated with granular roads. These characteristics are rutting, washboarding, potholes, loose aggregate, dust, crown, and drainage. The condition (or severity) of each characteristic can be expressed on a numeric scale from 1 to 9, with 9 representing the best possible condition, and 1 denoting the worst condition. A detailed table named "surface condition rating report" was developed and presented to each survey participant in order to assist survey participants in objectively assessing the condition of their granular roads. This table can be found in Appendix C of this report.

Figure 4-14 illustrates the average score (i.e., condition) and the average threshold score to trigger resurfacing work for the 20 Iowa counties that responded to the survey.

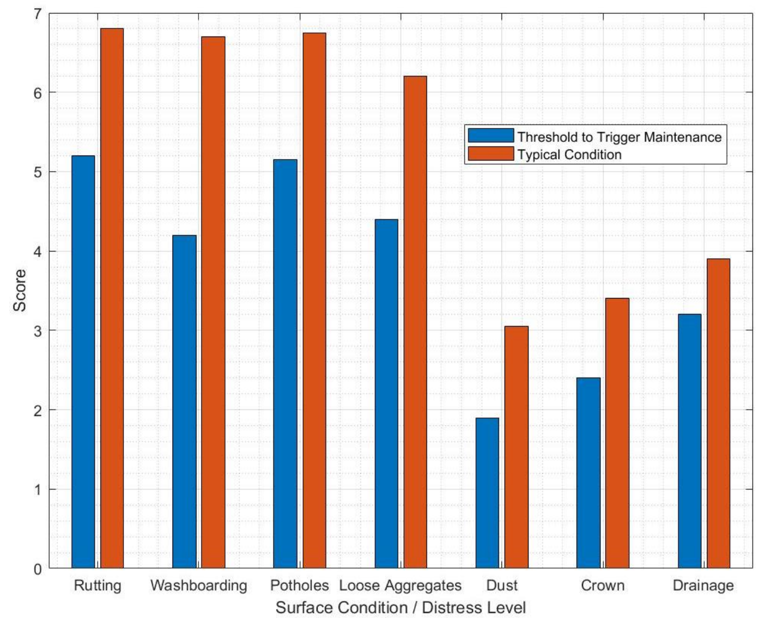


Figure 4-14. Surface condition rating

Note that the maximum score for rutting, washboarding, potholes, and loose aggregates was 9. The maximum score for dust, crown, and drainage were 4, 3, and 5, respectively. Figure 4-14 shows that the typical condition is greater (i.e., better) than the threshold score for all seven characteristics.

Figure 4-15 depicts the results obtained from survey participants on the relative influence of possible factors affecting the deterioration of granular roads.

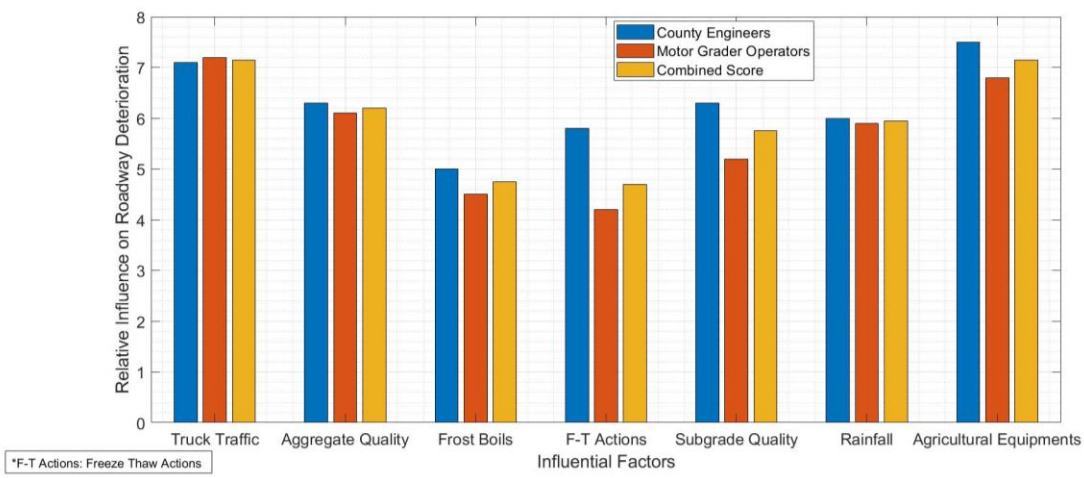


Figure 4-15. Ranking of granular roadway deterioration influential factors

Six influential factors were previously identified and provided by the research team in the survey questionnaire. However, the survey participants also had the option to provide additional factor(s). Survey participants expressed the influence of each factor on a scale of 1 to 9, with 1 being the least influential and 9 being the most influential.

A substantial number of respondents reported traffic generated by agriculture activities (both farming and livestock cultivation) as one of the factors causing deterioration of granular roads in their respective location. Based on the responses, it became clear that local granular roadways received a significant amount of heavy traffic loading from agriculture equipment such as manure tankers (from farming activities) and feed trucks (from animal confinement). Due to the popularity of this factor among survey participants, the research team decided to include it in the analysis of influential factors (Figure 4-15).

Figure 4-15 shows, in general, both truck traffic and traffic from agricultural activities, were rated as the most influential factors on the deterioration of granular roadways. However, it is important to note that there may be some overlapping between these two factors, since truck traffic can be represented by either of the factors depending on the situation. Nonetheless, it is clear that heavy traffic loading, regardless of its application, had the most influence on the deterioration of granular roadways.

Figure 4-15 also shows that, in general, among the seven factors, frost boil was rated as the factor that has the least amount of influence on the deterioration of granular roadways. Table 4-7 tabulates the ranking of influential factors associated with granular roadway deterioration based on the survey responses from both county engineers and motor grader operators.

Table 4-7. Ranking of granular roadway deterioration influential factors

Overall rank	Overall influence score	Influential factor
1 (most influential)	7.18	Truck traffic
2	7.15	Others: Traffic caused by agriculture activities
3	6.25	Aggregate quality
4	5.98	Rainfall
5	5.83	Subgrade quality
6	5.06	Freeze-thaw action
7 (least influential)	4.74	Frost boils

Data Analysis

Gravel Loss Prediction Model

In multiple linear regression (MLR), the output results are assumed to have a linear relationship with the input variables. A typical form of MLR is shown in equation 7.

$$y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n \quad \textbf{(7)}$$

where, y is predicted responses, b_0 is intercept term, and $x_1, x_2, \ldots x_n$ are influential factors with corresponding coefficients of $b_1, b_2, \ldots b_n$.

The assumption of linear relationships in granular roadway deterioration processes showed satisfactory performances in previous studies (Paterson 1991). Cross validation is conducted to assess whether the model can generate satisfactory results for generalized independent data sets. In factorial design experiments, input variables are labeled as different levels or factors instead of using exact numerical values for analysis like ordinary regression.

Beta distributions are versatile, and therefore, they can be useful to model with a wide range of uncertainties. Linear regression assumes a symmetric normal distribution whereas beta regression analysis can assume flexible shapes depending on the nature of the data sets and thus, provide reliable estimations. Beta distributions are proven efficient in "rate" estimation (Ferrari and Cribari-Neto 2004) and therefore, may provide a better prediction in gravel loss modeling. A typical form of beta regression is shown in equation 8.

$$y = \frac{1}{\left(1 + e^{-(b_0 + x_1 b_1 + x_2 b_2 + \ldots + x_n b_n)}\right)} \quad \textbf{(8)}$$

where, y is the output predictor, b_0 is constant intercept term, and $b_1, b_2, \ldots b_n$ are coefficients for corresponding influential variables $x_1, x_2, \ldots x_n$.

Zone averages of AADT, annual precipitation, subgrade soil quality, LA abrasion, and fines content of aggregate (rock) materials variables were used to predict the annual gravel loss, and the single and double predictor model from MLR and beta regression (BR) were chosen as the estimated gravel loss.

The sensitivity of the models was analyzed in terms of the changes in output values expressed as a percentage of the change in input values, as shown in equation 9:

$$PC = \frac{\Delta Y}{\Delta X} \quad \textbf{(9)}$$

where, PC is the percent change in output results, ΔY is the change in granular roadway thickness, and ΔX is the change in an input value.

Drainage Factor

The impact on granular roadway deterioration processes caused by roadway drainage conditions was quantified in Huntington and Ksaibati (2007). The roadway drainage class used for their Wyoming studies were correlated with the AASHTO drainage classification from Richardson et al. (1996), and drainage coefficients were developed as shown in Table 4-8.

Table 4-8. Gravel loss coefficients based on roadway drainage conditions

Drainage class	Time required to drain water from layer(s)	Drainage coefficient
Very poor	Does not drain	2.00
Poor	30 days	1.50
Fair	7 days	1.00
Good	24 hours	0.50
Very good	2 hours	0.25

The coefficients range from 0.25 (very good drainage) to 2.00 (very poor drainage). Drainage coefficients were extrapolated based on the Wyoming studies to adjust for different roadway drainage conditions. The gravel loss estimation needed to be updated based on the corresponding drainage coefficients. A coefficient for fair drainage condition was assumed as a unit, and based on the factors from the Wyoming studies, coefficients for the remainder of the drainage conditions were calculated.

Survival Analysis

Survival analysis can handle the data censoring, which is a common occurrence in roadway management data and has been successfully employed in infrastructure management (Chen et al. 2015, Dong and Huang 2014, Park et al. 2016).

Survival analysis can predict the expected time for a certain random event to happen. In this study, survival analysis was applied to predict when the roadway system will reach a predefined undesired reliability. The approach has been proven to yield better estimations for failure prediction of roadway systems (Donev and Hoffmann 2019).

The roadway condition and performance database developed from the October 2018 survey was used to model when the roadway thickness would reach below 2 in. The 2 in. cut-off margin was determined from survey responses as shown in Figure 4-16.

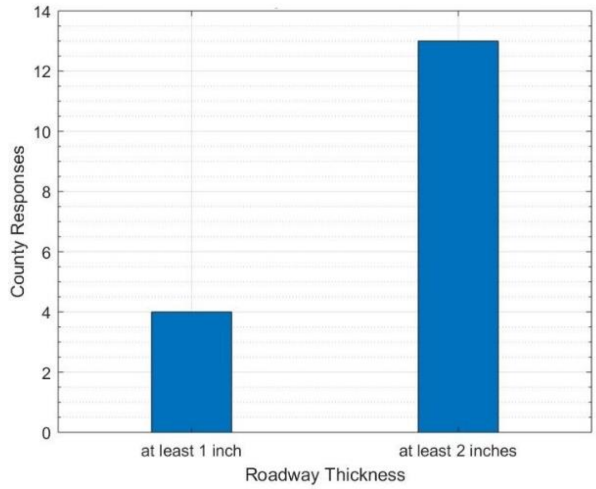


Figure 4-16. Minimum acceptable roadway thickness

Survival analysis was applied to identify the percentage of roads that will reach 2 in. in thickness after one year, indicating immediate attention is required. Weibull distribution was assumed for survival probability models. The typical form of the Weibull survival function is shown in equation 10, and the minimum annual aggregate (rock) requirements for gravel roads resurfacing purposes were calculated using equation 11.

$$s=1-e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{10}$$

$$M=P\times L\times W\times \Delta t\times \gamma \tag{11}$$

where,
s = the survival probability
t = time required to reach failure
β = the shape parameter controlling the deterioration rate
η = the scale parameter indicating the location of the average
M = the aggregate (rock) mass required
P = the failure probability, which is an additive inverse of survival probability and indicates the percentage of entire roadway that has thickness less than 2 in.
L = the total length of roadway system
W = the average width of the granular roadway network
Δt = the thickness of aggregate (rock) required for different treatment practices
γ = aggregate (rock) unit weight assumed of 115 pcf

Traffic compaction was defined as the reduction in initial thickness of a newly constructed/resurfaced granular roadway within a short period of time due to initial rutting and settlement of aggregate (rock) materials. Previous studies found that traffic compaction could cause up to 30% loss of initial roadway thickness (Paige-Green 1989). However, consultation with experienced professionals in this field suggested that this reduction may be higher, and therefore, it was assumed that 50% of roadway construction thickness would be lost within a short period of time due to traffic compaction.

Material Indexing

As evidenced from survey analysis, local agencies typically evaluate the aggregate (rock) material qualities based on visual inspection. This study recommends a scientific approach to assess the aggregate (rock) qualities. A material indexing formula was designed to correlate the aggregate (rock) material quality with granular roadway performance. Thus, it would enable local agencies to understand the benefits and risks associated with application of different aggregate (rock) materials in roadworks. The annual gravel loss formula developed in this study was used to estimate the expected gravel loss for varying aggregate (rock) materials. In Table 4-9, the aggregate (rock) materials are ranked based on such values.

Table 4-9. Material indexing

Material loss type	Annual gravel loss (in.)
Unacceptable	≥ 0.90
Poor	< 0.90
Fair	< 0.60
Acceptable	< 0.30

Network Performance

The roadway reliability was designed based on the existing roadway network thickness. Based on the survey responses, 5 in. of roadway thickness was defined as an excellent system with 100% reliability, whereas existing roadway thickness was defined as an unacceptable system at 50% reliability. Any reliability below 50% is undefined since that corresponds to complete roadway system collapse and reconstruction is warranted. Roadway reliability and system at risk are calculated with equations 12 and 13, respectively.

$$LOS_t = SNC\frac{t-t_0}{\frac{t_m-t_0}{6}} \quad \textbf{(12)}$$

$$SR_t = 1 - LOS_t \quad \textbf{(13)}$$

where, $LOS_t$is the roadway reliability for thickness t, SNC is the coefficient for standard normal conversation, t_m and t_0 are desired roadway thickness (5 in.) and existing roadway level thickness, respectively, and SR_t is the roadway system level at risk for thickness t.

The roadway system at risk was calculated as an inverse additive to reliability, where 5 in. of roadway thickness corresponds to 0% system at risk. Reliability increases with the application of aggregate (rock); the shape of this increase was assumed to follow a normal distribution. Verbal representation of roadway network performance with reliability is shown in Table 4-10.

Table 4-10. Verbal representation of roadway reliability

Reliability	Network performance
50–60%	Marginal
60–70%	Fair
70–80%	Good
80–90%	Very good
90–100%	Excellent

Results

Factorial design experiment analyses yielded a perfectly fitted model, since there were no degrees of freedom as shown in Table 4-11.

Table 4-11. Properties of factorial design experiment

Property	Value
R-square	1
Degrees of freedom	0
F-statistics	NaN
t-statistics	NA

NaN=not a number, NA=not applicable

It is implied that assuming the gravel loss deterioration factors to be different levels, or factors, was ineffective. Factorial designs produce the most reliable what-if scenario predictions for controlled experiments. However, in this study adequate information on roadway deterioration influential factor-to-factor interactions were not available, which may be responsible for ineffective performance of this factorial experiment.

MLR analysis was conducted to predict annual gravel loss. R-square, root mean square error (RMSE) and leave one out cross validation (LOOCV) values were calculated for each of the roadway deterioration influential factors (i.e., AADT, annual precipitation, subgrade soil quality and aggregate quality) to identify the best gravel loss predictors. A summary of this data was presented under Data Collection earlier in this chapter, and the full data set is available in Appendix D. In MLR analysis, the best single predictor for annual gravel loss estimation was found to be LA abrasion values of aggregate (rock) materials, and the best two predictors were LA abrasion and percentage finer than #200 sieve of aggregate (rock) materials. A two-predictor variable model was chosen because of its higher R-square value, and its properties are illustrated in Table 4-12.

Table 4-12. Properties of simplified MLR gravel loss model

Input variables	LA abrasion	LA abrasion, PF
R-square	0.25	0.93
RMSE	0.09	0.09
Intercept	0.22	-1.79
Coefficient for LA abrasion	0.011	0.048
Coefficient for percentage finer than #200 sieve		0.073
Range of values for LA abrasion	31–41%	31–41%
Range of values for percentage finer than #200 sieve		6.5–9%
LOOCV–R-square	NA	0.30
LOOCV–RMSE	NA	0.25

LA=Los Angeles, PF=percent fines, NA=not applicable

In the BR analysis, Los Angeles (LA) abrasion values were used as the single predictor model, and percent fines (PF) and AADT were identified as the best two predictors to estimate gravel loss. The properties of the beta regression model are shown in Table 4-13.

Table 4-13. Properties of BR gravel loss prediction model

Input variables	LA abrasion	AADT, PF
R-square	0.82	0.95
Log-likelihood	-6.11	-7.53
Intercept	-6.33	-7.53
Coefficient for LA abrasion	0.18	
Coefficient for percentage finer than #200 sieve		2.41
Coefficient for AADT		0.15
Range of values for LA abrasion	31–41%	
Range of values for percentage finer than #200 sieve		6.5–9%
Range of values for AADT		41 – 76
P-value for LA abrasion	<0.0001	
P-value for percentage finer than #200 sieve		<0.0001
P-value for AADT		<0.0001

LA=Los Angeles, PF=percent fines, AADT=annual average daily traffic

Annual gravel loss was estimated as the arithmetic average of the single and double predictor BR models after comparison with field performance, and the prediction expression is shown in equation 14.

$$AGL=D_r*\frac{\frac{1}{1+e^{-(Intc_{1pm}+LAA*Cf_{LAA})}}+\frac{1}{1+e^{-(Intc_{2pm}+AADT*Cf_{AADT}+PF*Cf_{PF})}}}{2} \quad \textbf{(14)}$$

where, AGL is annual gravel loss in inches; D_r is drainage coefficient; $Intc_{1pm}$ and $Intc_{2pm}$ are the intercepts for 1 and 2 predictor models, respectively; and LAA, PF, $AADT$, Cf_{LAA}, Cf_{PF}, and

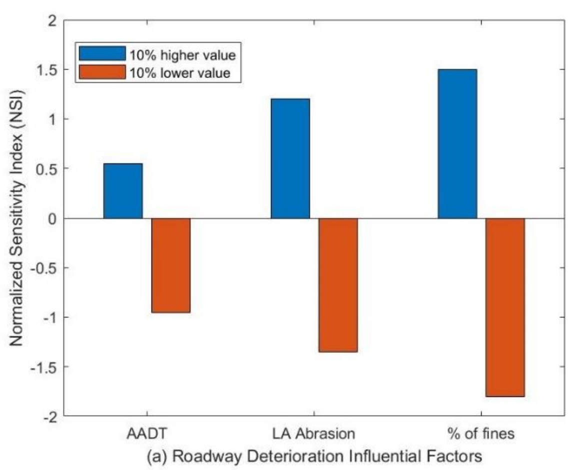
Cf_{AADT} are values and coefficients for Los Angeles abrasion, percent fines, and annual average daily traffic, respectively.

In Table 4-14, the gravel loss observed at the test section in Decatur County, Iowa for the *TR 704 Performance-Based Evaluation of Cost-Effective Aggregate Options* project is compared with estimations from the BR model.

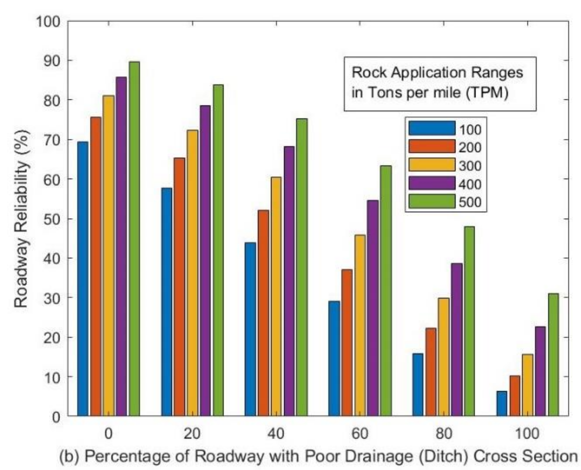
Table 4-14. Comparison of observed annual gravel loss with BR model

Aggregate used in field observation site	Observed average annual gravel loss (in.)	Estimated annual gravel loss (in.) BR model
BFL Class A (local material)	1.09	1.04

The BR model yields a reasonably satisfactory performance with simpler inputs. Sensitivity analysis of this model is shown in Figure 4-17.



(a)



(b)

Figure 4-17. Sensitivity analysis of BR model

Figure 4-17a indicates percent fines as the most sensitive input parameter. Figure 4-17b shows the sensitivity of the drainage condition and its impact on roadway reliability. Figure 4-17b shows how roadway reliability drops when the percentage of roadway with a poor drainage (ditch) cross section increases from 0% to 100% for aggregate (rock) application rates of 100, 200, 300, 400, and 500 TPM.

To determine the sensitivity of the input variable AADT in annual gravel loss prediction, the AADT values for Decatur County were changed by ±10% while the remainder of the input variables (i.e., PF and LA abrasion) were kept constant. To determine the sensitivity of the input variable LA abrasion in annual gravel loss prediction, the LA abrasion values of aggregate materials used for the test site construction in Decatur County were changed by ±10%, while the remainder of the input variables (i.e., AADT and LA abrasion) were kept constant. To determine the sensitivity of input variable PF in annual gravel loss prediction, the PF values of aggregate materials used for the test site construction in Decatur County were changed by ±10% while the remainder of the input variables (i.e., AADT and LA abrasion) were kept constant. Properties of aggregate materials used for the test site construction were shown under Data Collection earlier in this chapter.

Results of the BR model were compared with the HDM-4 model results, since it was considered as the most effective gravel loss prediction model, other gravel loss models discussed previously under Background in Chapter 2 were proven highly sensitive to all input variables, and therefore, they were not explored in this study. Sensitivity analysis results of the HDM-4 and BR models are illustrated in Figure 4-18.

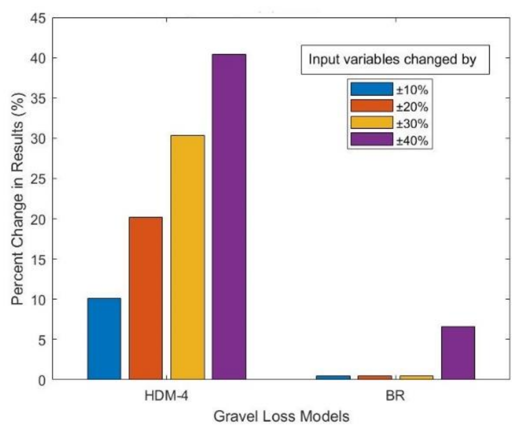


Figure 4-18. Sensitivity analysis of HDM-4 and BR models

In case of the BR model, gravel loss estimation remains unchanged for 10%, 20%, and 30% deviations in LAA, AADT, and PF, whereas gravel loss estimation changes by approximately 6.6% for 40% deviations in LAA, AADT, and PF. In the case of the HDM-4 model, 10%, 20%, 30%, and 40% variations of all input variables (i.e., Kgl, MMP, RF, AADT, Kkt, C, P075j, and PIj) yielded almost linear variations in gravel loss estimation by approximately 10.1%, 20.2%, 30.3%, and 40.3%, respectively. The HDM-4 model showed highly sensitive linear behavior, which is unlikely to be a proper representation of gravel loss mechanisms.

With a 10% variation in daily traffic, Los Angeles abrasion values and fines content of the gravel material represent only slight differences in daily traffic and material quality, and their effects on gravel loss are thus unlikely to be significantly different. The shape of the BR distribution model was designed in such a way to control the response variable against minor variations in input variables. Therefore, the BR model showed significantly rigid behavior for variations up to 30% in the input variables, which could easily result from a lack of adequate data points.

Sensitivity analysis for each input variable for the HDM-4 model reveals that its underlying contributing factor is the gravel material loss calibration factor, Kgl, as shown in Figure 4-19.

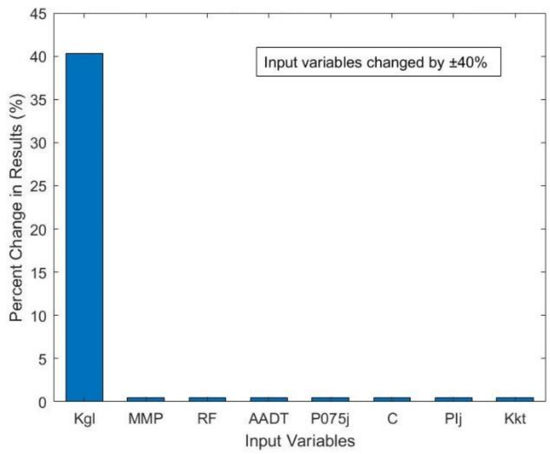


Figure 4-19. Sensitivity analysis of HDM-4 model

Kgl controls the entire shape of the HDM-4 model, and even when the variables were changed by 40%, only Kgl showed an effect on the output. The HDM-4 model should be calibrated with extensive field observations over several years. However, local agencies constantly struggle with limited budgets and such extensive field observations may not be economical, and therefore, the HDM-4 model may not be a feasible gravel loss estimation tool for them.

Input requirements for BR and HDM-4 gravel loss prediction models are shown in Table 4-15.

Table 4-15. Input requirements for HDM-4 and BR models

User input category	Required input
Common for HDM-4 and BR models	1. Average annual daily traffic 2. Gravel material passing #200 sieve
Additional for HDM-4 model	1. Average rise and fall of the road 2. Mean monthly precipitation 3. Traffic-induced material chip off coefficient 4. Gravel material loss calibration factor 5. Average horizontal curvature of the road 6. Plasticity index of material 7. Traffic induced material loss calibration factor

Although the HDM-4 model yielded better performance than the BR model, local agencies may be unable to adopt the HDM-4 model, since the collection of such high-quality and large volumes of data may be practically impossible. In the case of the BR model, such information is analyzed beforehand during the model development phase, and therefore, the finalized BR model can yield satisfactory results with limited user inputs.

Material indexing was performed as a function of annual gravel loss based on the methodology previously explained. A sample matrix of indexed aggregate materials is shown in Table 4-16.

Table 4-16. Aggregate material indexing

AADT	Percent finer than #200 sieve for aggregate (rock) materials (%)	Los Angeles abrasion values of aggregate (rock) materials (%)	Material index
76	6.65	39	Fair
56	8.25	40	Poor
49	7.89	32	Poor
41	8.67	33	Fair

Annual gravel loss is influenced directly by AADT, percent fines, and LA abrasion values of aggregate materials and indirectly by subgrade soil quality, roadway drainage condition, and annual precipitation.

After estimation of the annual gravel loss, the GRAMS tool needs to be executed, and survival model simulations would identify the minimum aggregate (rock) requirements to keep the roadway network operational at the desired reliability.

A sample analysis is presented herein to illustrate how the survival model simulation and aggregate (rock) estimation calculation is conducted as shown in Table 4-17 and 4-18.

Table 4-17. Weibull parameters at 95% confidence interval based on loglikelihood method

County	Weibull scale parameter, η	Weibull shape parameter, β
Allamakee	5.58	4.17
Clay	1.85	4.81

Table 4-18. Estimated minimum resurfacing aggregate requirements for Clay County after 1 year

Resurfacing practice (Δt in in.)	Aggregate (rock) requirement (tons)	Tons per mile for resurfacing
0.50	23,000	600
0.75	35,000	900

In this sample calculation, data from Clay and Allamakee counties were used to generate an inventory of granular roadway network conditions, along with a time-series model and failure criteria for granular roadways based on granular surface thickness. The expected lifetime probability distribution for the entire granular roadway network was predicted using survival function. A parametric model (i.e., Weibull) was chosen because non-parametric models could not predict outside of the data set. The fitted survival models were validated based on the corrected Akaike information criterion (AICc), Bayesian information criterion (BIC), and loglikelihood method. For a range of different treatment practices, the most effective ones can be determined from the budget and reliability considerations. Similar calculations were conducted for other Iowa counties, and the GRAMS tool conducts such an analysis for each county.

The shape parameter (β) is related to the system failure rate and controls the shape of the distribution, whereas changes in the abscissa (time) in the distribution are represented by the scale parameter (η). Although both counties had a similar distribution shape, a higher percentage of granular roadways were predicted to fail in Clay County after a given time due to its smaller scale parameter compared to Allamakee County, which was evident in the Weibull survival curves as shown in Figure 4-20, where the collected data points (represented by black dots) are closely aligned with the fitted models (represented by green curves).

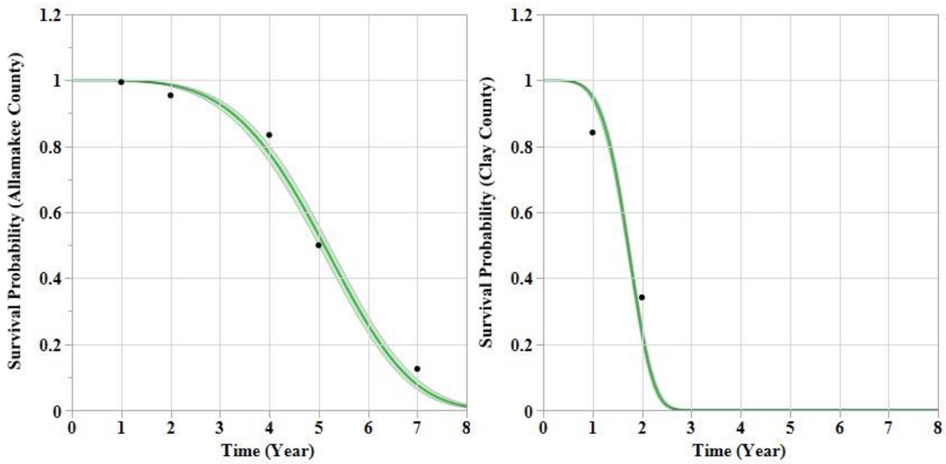


Figure 4-20. Weibull distribution-based survival curves for Allamakee and Clay counties

The survival models predicted the minimum percentage of roads that would require resurfacing treatments after a certain time. For example, after one year, about 5% of granular roads in Clay County would fall below the threshold criteria for minimum thickness.

Historical aggregate (rock) application data provided by Clay County revealed that over the last few years, Clay County applied approximately 100,000 to 120,000 tons of aggregate (rock) each year, which may imply, for resurfacing purposes, they apply 0.50 to 0.75 in. of aggregate (rock) to the failed roads (23,000 to 35,000 tons) and utilize the rest of the materials for minor roadworks and spot rocking purposes. The analyses herein inferred that Clay County shows a higher reliability concern for granular roadway management, since they have been conducting significant spot rocking work along with required minimum annual resurfacing treatment.

Based on the unit cost price, the risk and cost curves were generated in the GRAMS analysis. A basic explanation of how to use the GRAMS tool interface is discussed in Chapter 5. The next chapter also includes the iteration for 0% to 100% roadway risk level, along with budget and aggregate (rock) requirements, are simulated in the GRAMS tool execution through back-end calculation, and therefore, such analysis of the GRAMS tool is graphically represented.

CHAPTER 5. GRAMS INTERFACE

Input Screen

After launching the GRAMS tool, the following input parameters are required to estimate the aggregate (rock) requirements in the GRAMS tool as shown in Figure 5-1.

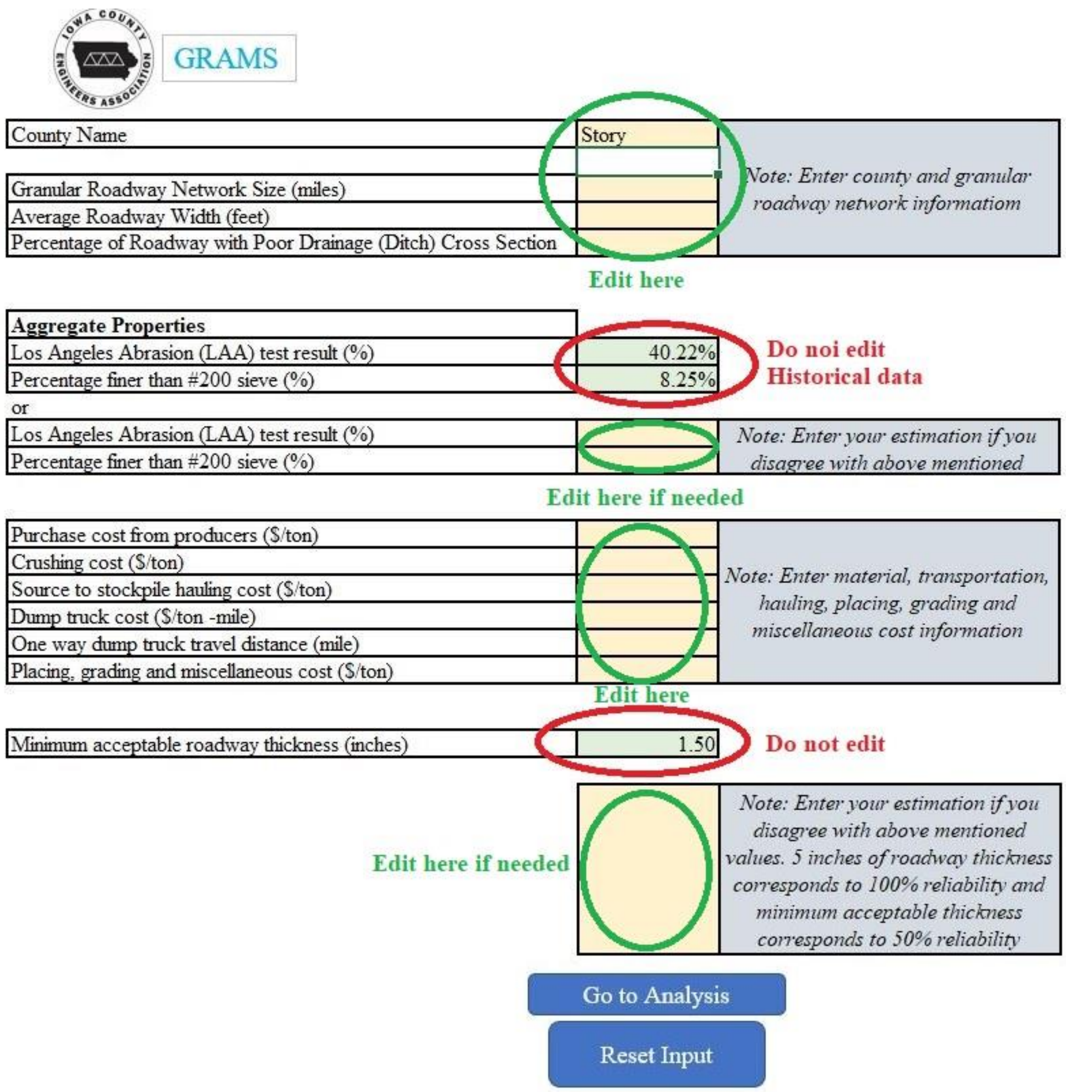


Figure 5-1. Input screen of GRAMS tool

The cells circled in red represent historical data, and editing the data contained in those cells will create a malfunction of the tool. Only the yellow colored cells, circled in green, are meant for user input. The users' manual of the GRAMS tool, which will be offered as a separate document, provides detailed explanation on this matter.

The cells that require input from users are as follows:

- County Information
  - County Name
  - Granular Roadway Network Size
  - Average Width of Granular Roadway
  - Percentage of Roadway with Poor Drainage (Ditch) Cross Section
- Aggregate (Rock) Quality Information
  - Los Angeles (LA) Abrasion (%)
  - Fines Content (%)
- Cost Information
  - Material Cost
  - Crushing Cost
  - Hauling Cost
  - Transportation Cost
  - Placing, Grading and Miscellaneous Cost
- Reliability Information
  - Minimum acceptable roadway thickness (inches)

Analysis

Roadway inventory information is needed in the aggregate (rock) requirement estimates tab in order to execute the program as shown in Figure 5-2.

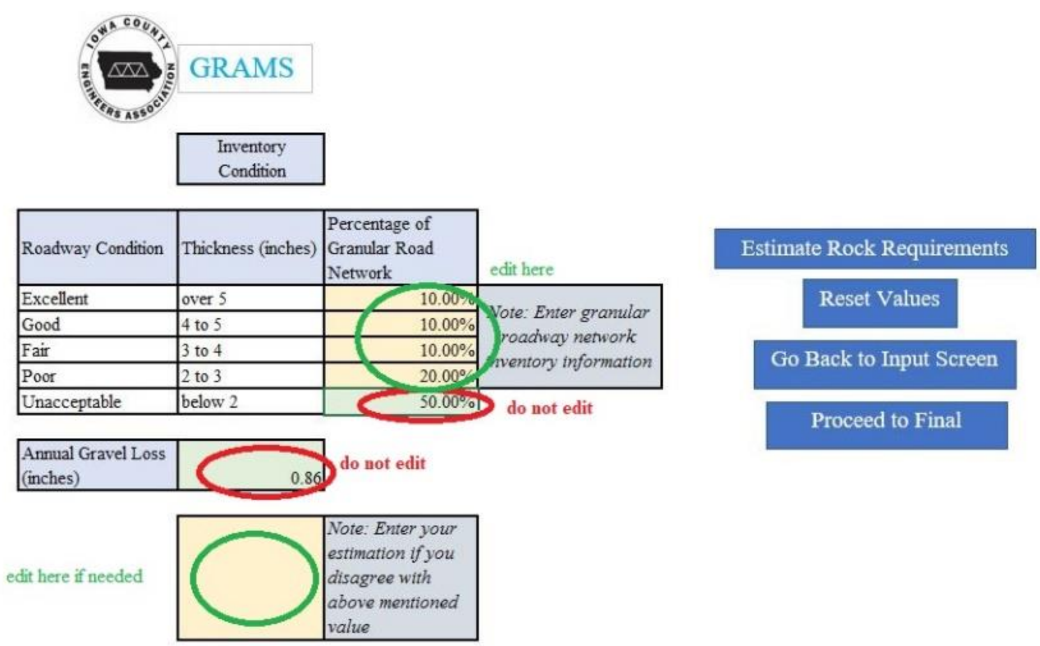


Figure 5-2. Analysis tab of GRAMS tool

Final Report

In the final report tab, the user can simulate the aggregate (rock) requirements along with a budget estimation for varying roadway reliability as shown in Figures 5-3 and 5-4.

GRAMS

County	Story
Most Critical System Size (miles)	5.21

Range of Options	
Rock Application Case (miles)	300.00

Ton per Mile (TPM)	Rock Quantity (Ton)	Total Cost ($)	Material Cost ($)	Level of Service (%)	System Performance
100	30,000	$330,000	$90,000	53.01%	Marginal
200	60,000	$660,000	$180,000	60.92%	Fair
300	90,000	$990,000	$270,000	68.41%	Fair
400	120,000	$1,320,000	$360,000	75.20%	Good
500	150,000	$1,650,000	$450,000	81.13%	Very Good

Figure 5-3. Final report of GRAMS tool

	Range of Option
Rock Application Case	50%
Miles	150.00

edit here

Figure 5-4. Range of options simulator

The user can choose to apply aggregate (rock) to the entire roadway network or a portion of the network and generate the corresponding risk versus cost curves accordingly.

Risk Curves

Risk curves provide a range of aggregate application options (in terms of tons per mile [TPM]) for users to choose from varying budget conditions as shown in Figures 5-5 and 5-6.

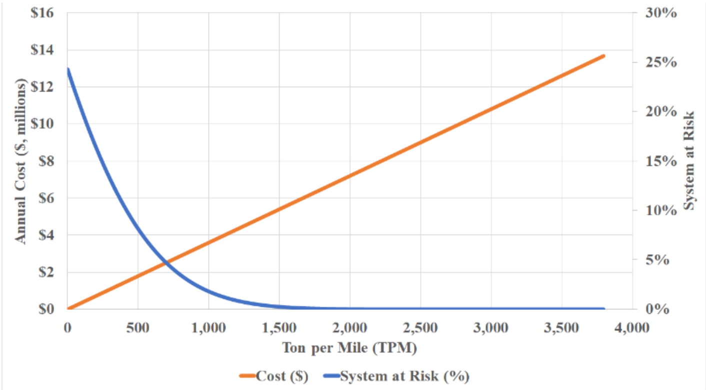


Figure 5-5. Risk vs. total cost

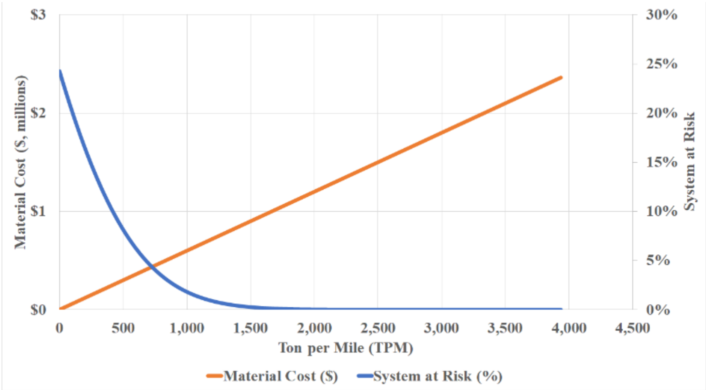


Figure 5-6. Risk vs. material cost

Such curves provide risk percentages of the roadway system for each budget and aggregate (rock) application condition, thus enabling the user to make engineering decisions. The roadway lifetime distribution is illustrated in Figure 5-7, which depicts the timeline of a newly constructed granular roadway system to completely fail if no maintenance activities are performed.

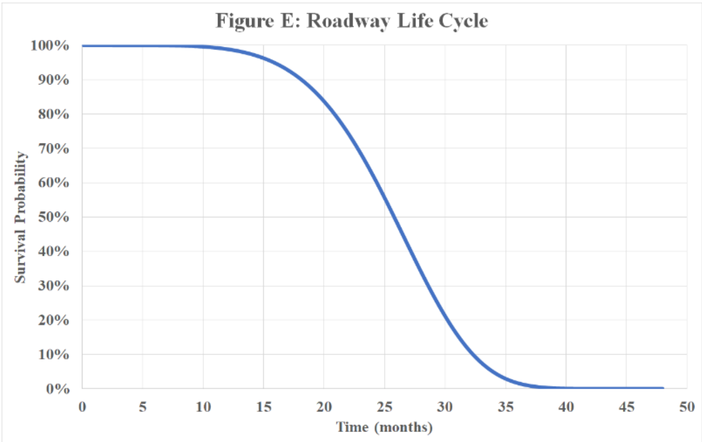


Figure 5-7. Roadway lifetime distribution

Simulated Case Study—Story County

In this section, a case study is simulated for Story County, Iowa in the GRAMS tool, in which the annual aggregate (rock) and budget requirements are predicted. This case study illustrates how the GRAMS tool results can be used to make roadway maintenance decisions. In this simulation, the initial condition (i.e., system size, width, roadway thickness, and drainage condition) of the granular roadway network was assumed as shown in Tables 5-1 and 5-2.

Table 5-1. Roadway system properties (assumed)

Properties	Values
Granular roadway network size (miles)	300
Average roadway width (feet)	20
% of roadway with poor drainage (ditch) cross section	40

Table 5-2. Roadway inventory condition (assumed)

Roadway condition	Thickness (in.)	% of granular roadway network
Excellent	Over 5	10
Good	4–5	10
Fair	3–4	20
Poor	2–3	20
Unacceptable	Below 2	40

The performance of the Story County granular roadway network are predicted for two different aggregate (rock) materials. The aggregate (rock) material properties of the two types, X and Y, along with their associated costs are assumed as shown in Table 5-3.

Table 5-3. Aggregate (rock) properties (assumed)

	Aggregate type	
Data attributes	X	Y
LA abrasion values (%)	32	40
Percent finer than #200 sieve	6	8
Purchase cost – from producers ($/ton)	5	3.5
Crushing cost –if applicable ($/ton)		
Hauling cost –from sources ($/ton)	3	2.5
Dump truck cost ($/ton-mile)	0.30	0.25
One way dump truck travel distance (miles)	20	20
Placing, grading and miscellaneous cost ($/ton)	2	2

As shown in Table 5-3, the aggregate (rock) type X is better than type Y, because of its lower LA abrasion and percentage fines values, and therefore, the unit prices for type X is higher than for type Y.

With the data presented in Tables 5-1 through 5-3, the GRAMS tool was executed, and the results are shown in Tables 5-4 and 5-5.

Table 5-4. Aggregate (rock) and budget requirements (aggregate type X)

Ton per mile (TPM)	Rock quantity (ton)	Total cost ($)	Material cost ($)	Reliability (%)	System performance
100	30,000	$480,000	$150,000	86.44%	Very good
200	60,000	$960,000	$300,000	89.78%	Very good
300	90,000	$1,440,000	$450,000	92.49%	Excellent
400	120,000	$1,920,000	$600,000	94.61%	Excellent
500	150,000	$2,400,000	$750,000	96.22%	Excellent

Table 5-5. Aggregate (rock) and budget requirements (aggregate type Y)

Ton per mile (TPM)	Rock quantity (ton)	Total cost ($)	Material cost ($)	Reliability (%)	System performance
100	30,000	$390,000	$105,000	62.21%	Fair
200	60,000	$780,000	$210,000	69.31%	Fair
300	90,000	$1,170,000	$315,000	75.76%	Good
400	120,000	$1,560,000	$420,000	81.39%	Very good
500	150,000	$1,950,000	$525,000	86.13%	Very good

The results illustrate a hypothetical scenario of roadway system performance and reliability if the aggregate types of X and Y were to be used for maintenance work for one year. Tables 5-4 and 5-5 also present the annual aggregate (rock) requirements and budget estimates for each case. The benefits of using the superior quality aggregate (rock) material type X for maintenance work are evident in the analysis. For example, if the Story County engineer decides to allocate about $500,000 for aggregate (rock) material purchasing purposes, aggregate type X will provide about 93% reliability, whereas a similar budget would yield about 83% roadway reliability in the case of aggregate type Y. In addition, if the Story County engineer decides to allocate about $1,000,000 in total for roadway maintenance purposes, aggregate type X will provide about 90% reliability whereas a similar budget would yield 72% roadway reliability in the case of aggregate type Y.

Local agencies can conduct such trade-off analyses using the GRAMS tool to make maintenance decisions. In practice, local agencies have limited control over other influential factors affecting roadway deterioration (i.e., roadway traffic, precipitation amount, and subgrade soil quality). However, in the GRAMS tool, the impacts of such factors were analyzed as part of the background development of this tool, and users can alter the only variable (i.e., aggregate quality) that can be changed from a practical point of view.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

This project developed an Excel-based GRAMS tool that can help local agencies in Iowa consistently estimate annual gravel loss amounts and thus determine aggregate (rock) requirements for budgeting purposes. This tool is a network (county) level-based estimation tool that can estimate a range of gravel loss amounts and required rock quantities depending upon different target levels of service and performance. The tool is based upon survival analysis as a computational algorithm to estimate minimum annual aggregate (rock) requirements for various budget and risk scenarios. Thus, the tool offers a trade-off analysis of various aggregate (rock) materials and identifies the most effective and economical options. The gravel loss predictions estimated from the tool were compared to data obtained from a field test section in Decatur County, Iowa, which yielded similar results with smaller (<10%) percent errors.

Since the user-input data to run the GRAMS tool are readily available to local agencies, the tool is highly practical. One of the features of the developed GRAMS tool is that it is significantly sensitive to the roadway drainage condition (i.e., ditch depth, roadway crown, and cross section) and therefore, caution is advised with this input parameter.

One aspect that could be improved is that the tool is mostly based upon secondary data sets such as survey responses, empirical opinions, and a limited amount of historical performance data. For continuous improvement of this tool, the research team recommends a district-level granular roadway data collection effort and management assessment on a biannual basis. This study developed a roadway condition rating report (Appendix C) that can be filled out by a motor grader operator from each district twice a year to provide information on roadway performance and condition. Development of a historical database will enable better calibrating the modeling parameters used in the tool in the long run.

Effective data storage is also a requirement for continuous improvement of the tool. Geographic information system (GIS) software such as ArcGIS can provide a user-friendly interface for data storage and management purposes. It was found that about one-quarter of Iowa counties are currently using ArcGIS for data storage. Thus, this study recommends that local agencies use such GIS software programs to track their historical budgets as well as operations and maintenance activities.

The research team also recommends a three-year pilot project focusing on field monitoring in selected Iowa counties to further calibrate and validate the tool. The following steps may serve as a procedural guideline:

- Step 1: Select counties based on the geographic location and willingness to participate in the pilot program.
- Step 2: Develop a comprehensive roadway inventory: A detailed roadway condition database should be developed to collect and store required data for improving granular road asset management practices.

- Step 3: Select aggregate (rock) materials: Multiple road sections will be selected within each county and their performance under application of varying aggregate (rock) materials will be monitored.
- Step 4: Form a data matrix: The data set will include historical aggregate (rock) application and roadway performance data for each road section for every county, and will provide a summary of granular roadway deterioration phenomena for the entire state of Iowa.
- Step 5: Calibrate and validate the GRAMS tool: Observations from multiple years of field data will be used to calibrate the existing GRAMS model. The resulting next generation GRAMS 2.0 model will be released on a dynamic geomap-based online platform.
- Step 6: Add features to the tool that takes stabilization impact into account during asset management analyses.

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APPENDIX A. WEB SURVEY I - FEBRUARY 2018

Goal of this survey:

Thank you for your interest in our survey. The main purpose of this survey is to collect information about resurfacing and maintenance practices of Iowa county engineers for granular roadways. The survey is being conducted for the research project *TR-729: Development of Granular Road Asset Management System* **(GRAMS),** funded by Iowa Highway Research Board **(IHRB).** This project is endorsed by the Iowa County Engineers Association Service Bureau **(ICEASB).** The survey should take about 15 minutes to complete. We appreciate your time and assistance for the successful completion of the research project.

Benefit of Participation:

After completion of this project, we will provide you with an electronic copy of the final report along with an Excel Spreadsheet-based **GRAMS tool** if you complete this survey.

Please read the definitions of the terms below carefully before starting the survey. Thanks again for your time.

> **Definitions:**
> Resurfacing = a program that counties do every year on entire segments
> Spot rocking = spot maintenance of granular roadways (i.e., mud holes, frost boils)

Point of Contact:

If you have any questions about this research, feel free to contact:

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Assistant Professor, Department of Civil, Construction and Environmental Engineering
Town Engineering Building, Iowa State University
Ames, IA, 50011
Office Phone: 515-294-8158
Mobile Phone: 336-686-1361
Email: bcetin@iastate.edu

Please provide the following information:

County:
Contact Information:
Email:
Phone:

Question 1: What type of granular-surfaced road materials do you use for maintenance of gravel (i.e., crushed limestone or rounded natural gravel) roads? (Select all that apply.)

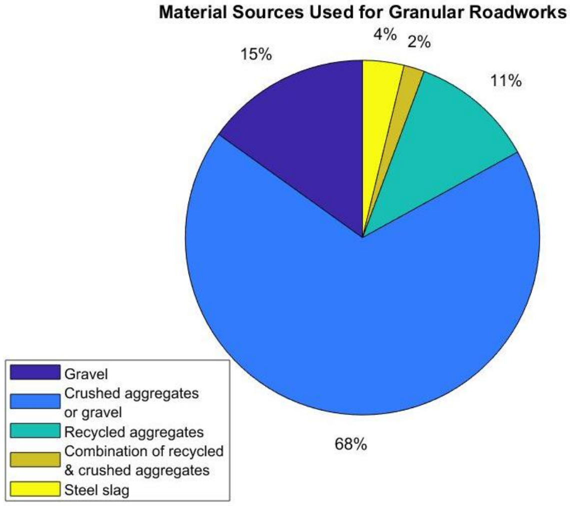


Figure A-1. Aggregate materials used for granular roadworks

Table A-1. Aggregate materials used for granular roadworks

Answer	Responses
Gravel from the pits / riverbeds	8
Crushed aggregates (limestone, dolomite, e.g.) or gravel	36
Recycled aggregates (recycled concrete aggregate, recycled asphalt pavement, etc.)	6
Combination of recycled aggregates and crushed aggregates	1
Steel slag	2
Other	0

Question 2: Based on your answer to Question 1, please enter the quantity of each material that you use in tons per year for maintenance?

Table A-2. Amount of aggregate material used

Material source	**Responses**	**Average quantity (tons)**
Gravel from the pits/riverbeds	9	45,556
Crushed aggregates (e.g., limestone, dolomite) or gravel	36	93,000
Recycled aggregates (recycled concrete aggregate, recycled asphalt pavement, etc.)	7	1,346
Combination of recycled aggregates and crushed aggregates	2	500
Steel slag	2	12,575
Other	0	N/A

Question 3: Based on your answer to Question 1, approximately how many tons per mile of the following materials do you apply per year for maintenance?

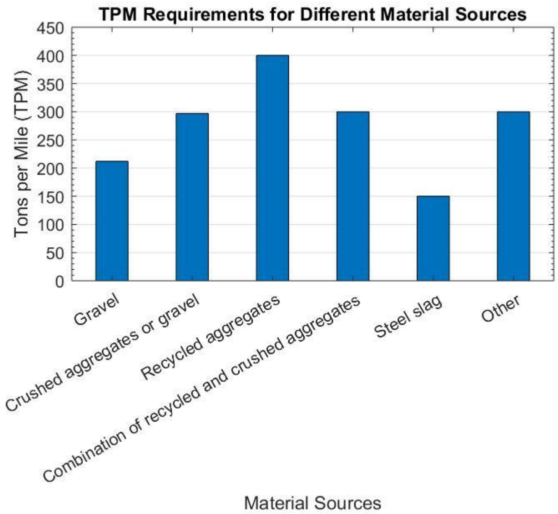


Figure A-2. Ton per mile aggregate requirements

Table A-3. Ton per mile aggregate requirements

Material source	Responses	Average quantity (TPM)
Gravel from the pits / riverbeds	8	212
Crushed aggregates (limestone, dolomite, e.g.) or gravel	34	297
Recycled aggregates (recycled concrete aggregate, recycled asphalt pavement etc.)	3	400
Combination of recycled aggregates and crushed aggregates	1	300
Steel slag	1	150
Other	1	300

Question 4: What are the typical maximum aggregate sizes used for your granular road surfaces?

Table A-4. Size of aggregate materials used

Answer	Responses
¾ inches	8
1 inch	23
1-¼ inches	4
1-½ inches	2
Other	2

Question 5: Do you have a county-specific granular road surface material gradation?

Table A-5. County-specific granular road surface material gradation

Answer	Responses
Yes	12
No	26

Question 6: What are your average hauling distances (in miles) from the stockpiles of different materials to the granular-surfaced roads?

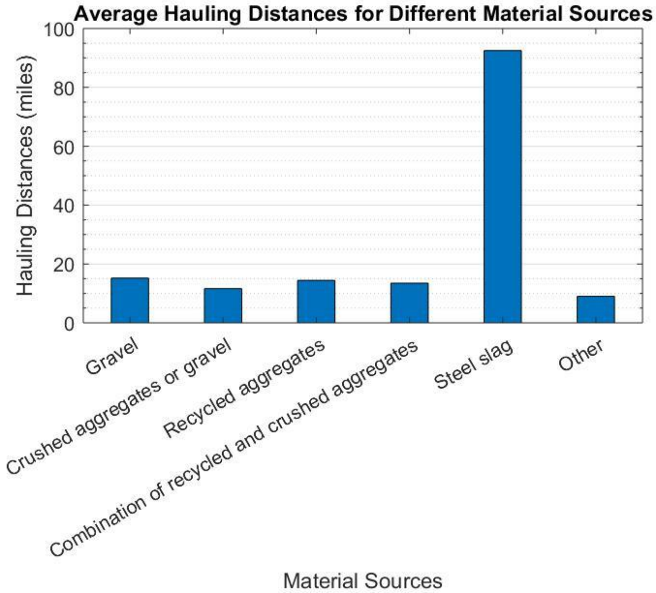


Figure A-3. Hauling distances from stockpiles

Table A-6. Hauling distances from stockpiles

Material source	**Average distances (mi)**	**Responses**
Gravel from the pits / riverbeds	15.22	9
Crushed aggregates (e.g., limestone, dolomite) or gravel	11.63	26
Recycled aggregates (recycled concrete aggregate, recycled asphalt pavement, etc.)	14.43	7
Combination of recycled aggregates and crushed aggregates	13.5	2
Steel slag	92.5	2
Other	9	1

Question 7: What is your average hauling distance (to the nearest mile) from the quarries/pits to the granular surfaced roads?

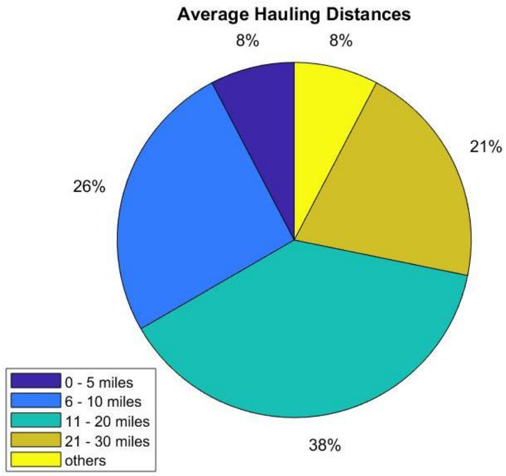


Figure A-4. Hauling distances from aggregate sources

Table A-7. Hauling distances from aggregate sources

Average hauling distances	Responses
0–5 miles	3
6–10 miles	10
11–20 miles	15
21–30 miles	8
Others	3

Question 8: Do you regularly resurface, or do you apply spot rock only?

Table A-8. Resurfacing and application of spot rock

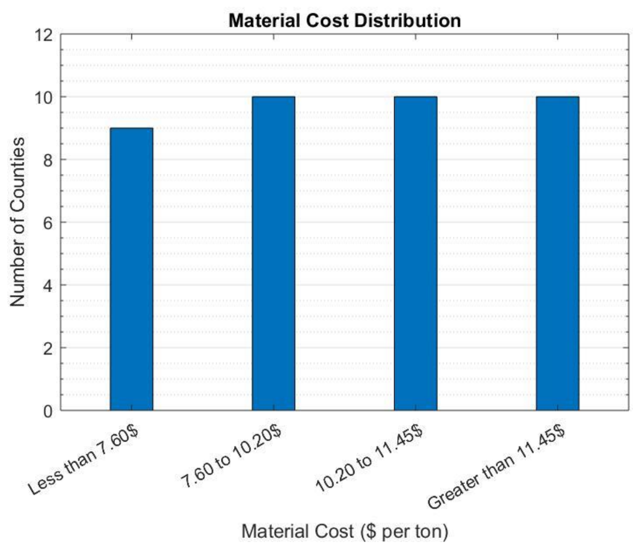
Answer	Responses
Resurface	4
Spot rock	7
Both	28

Question 9: What percentage of your granular roadway systems is resurfaced for the given periods below (not including spot rocking)?

Table A-9. Percentage resurfaced for each given period

Time frame	Average percentage of roadways resurfaced
< 1 year	15%
1–2 years	25%
3–4 years	26%
5–6 years	12%
> 7 years	7%

Question 10: What is the average cost (excluding hauling costs) of your main source of granular surface materials used for resurfacing?



Average materials cost = $9.37/ton with standard deviation of $3.15

Figure A-5. Material cost distribution

Question 11: How do you track your resurfacing program?

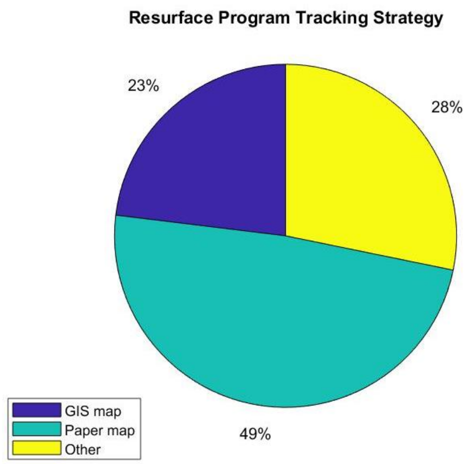
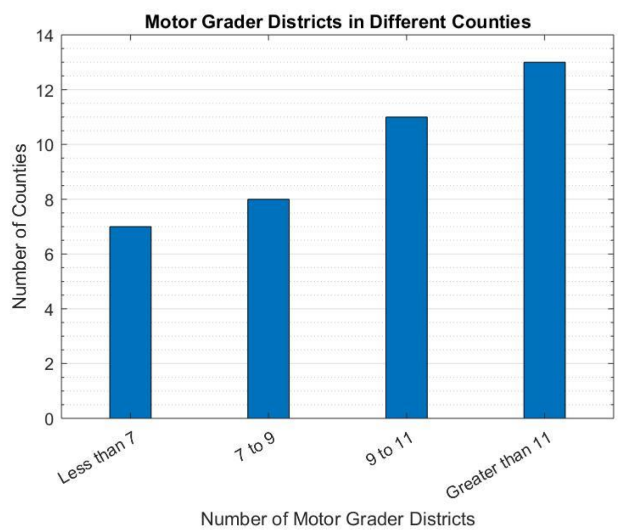


Table A-10. Resurfacing program mapping methods

Answer	Responses
GIS map	9
Paper map	19
Other	11

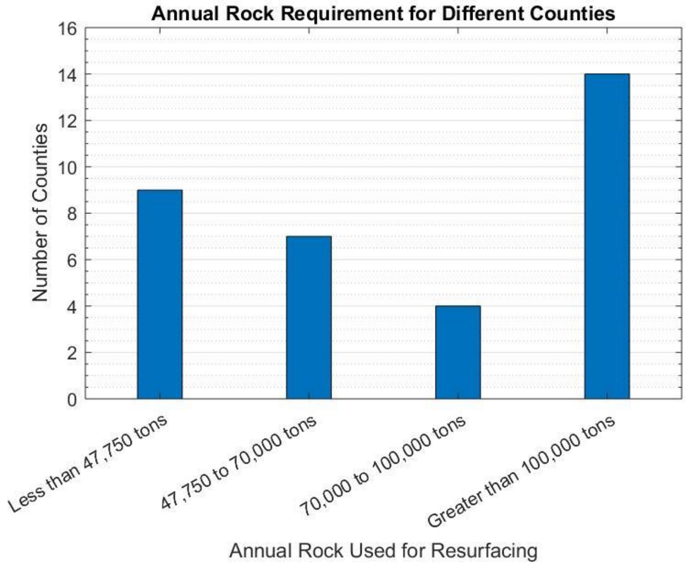
Question 12: How many motor graders districts do you have?



9 motor grader districts on average with standard deviation of 3.7 districts

Figure A-6. Distribution of grader district

Question 13: How many tons of material do you use per year for resurfacing of granular roads?



75,000 tons on average with standard deviation of 39,000 tons

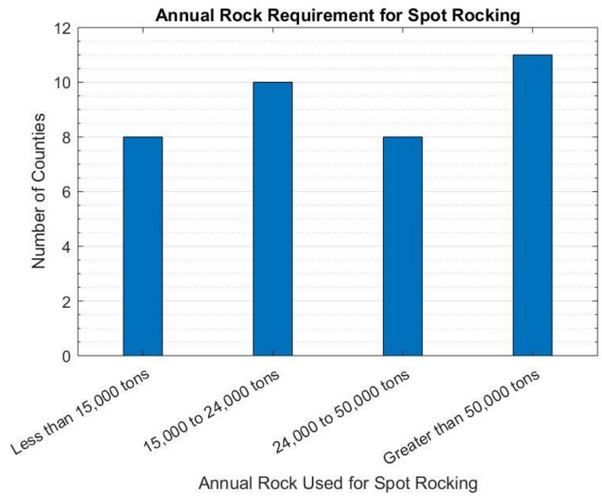
Figure A-7. Resurfacing aggregate requirement

Question 14: Do you record spot rocking quantity and location?

Table A-11. Spot rocking records

Answer	Responses
Yes	19
No	20

Question 15: How many tons of material do you use on average per year for spot rocking of granular roads?



39,000 tons on average with standard deviation of 46,000 tons

Figure A-8. Spot rocking requirements

Question 16: Are you using the rockalizer aggregate management system?

Table A-12. Use of rockalizer aggregate management system

Answer	Responses
Yes	5
No	34

Question 17: How does your agency evaluate the condition of granular roads? (Select all that apply)

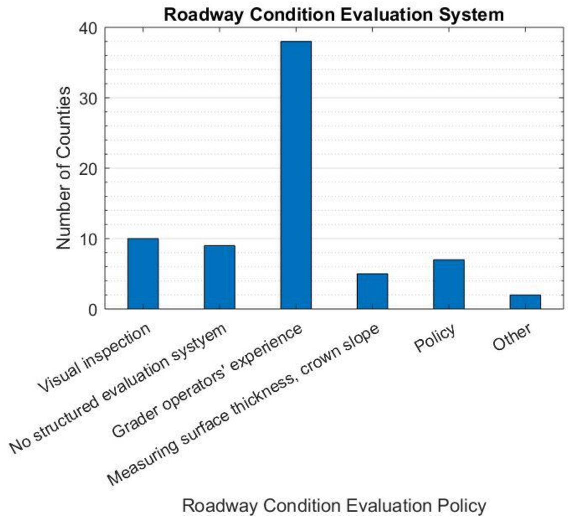


Figure A-9. Roadway condition evaluation system

Question 18: How does your agency determine the quality of aggregates? (Select all that apply)

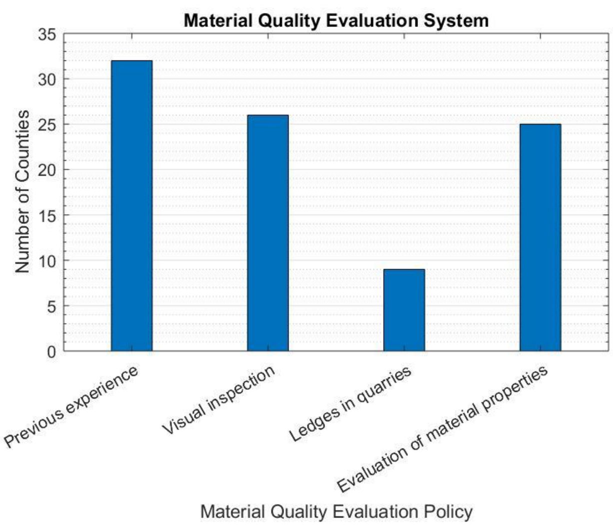


Figure A-10. Material quality evaluation system

Question 19: Does your agency keep good track of records for maintaining granular roads (select all that apply)?

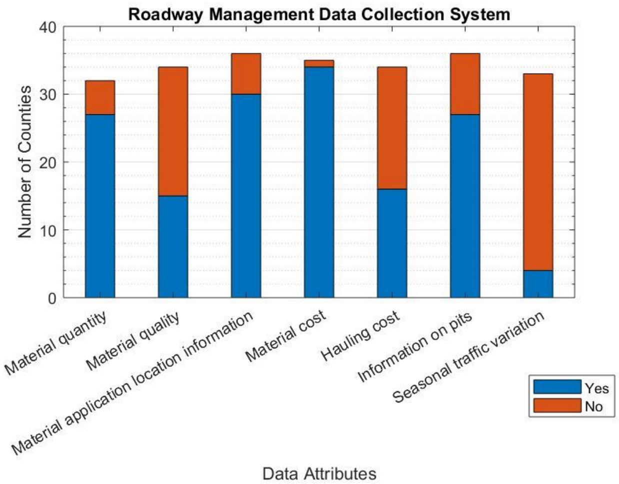


Figure A-11. Roadway management data collection system

Question 20: How does your agency determine the most economical way of purchasing and delivering aggregates? (Select all that apply)

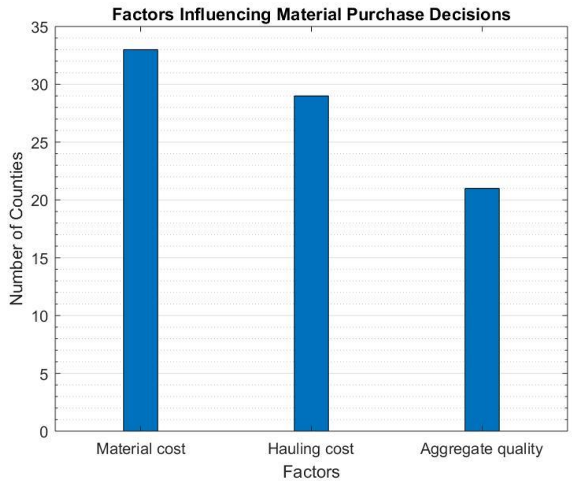


Figure A-12. Decision-making criteria

Table A-13. Decision-making criteria

Answer	Responses
Material cost	33
Hauling cost	29
Aggregate quality	21

Question 21: Do you feel like your county road system is…

Table A-14. Subjective county road system rating

Answers	Responses	
	Yes	No
Holding up	29	5
Improving	16	17
Regressing	8	23

Question 22: What percentage of your granular roadway materials were hauled by in the last 5 years?

Table A-15. Contractor vs. county haulers in the last 5 years

Answer	Percentage, on average
Contractors	36.28
County	63.72

APPENDIX B. WEB SURVEY II - OCTOBER 2018

Goal of this Survey

Thank you for your participation in our previous survey. The main purpose of this follow-on survey is to collect opinions and experiences from local county engineers and motor grader operators, in order to capture the perceived impact of several influential variables on granular road deterioration and on rock requirements to provide a satisfactory level of service.

The survey is being conducted for the research project *TR-729: Development of Granular Roads Asset Management System* ***(GRAMS)*****,** funded by the Iowa Highway Research Board **(IHRB).** This project is endorsed by the Iowa County Engineers Association Service Bureau **(ICEASB).** The survey should take about 15 minutes to complete. We appreciate your time and assistance toward the successful completion of the research project.

Point of Contact

If you have any questions about this research, feel free to contact:

Bora Cetin, PhD
Assistant Professor
Department of Civil, Construction and Environmental Engineering
Iowa State University
Town Engineering Building
Ames, IA, 50011
Office Phone: 515-294-8158
Mobile Phone: 336-686-1361
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Please return the completed survey electronically at shafkat@iastate.edu or mail copy at:

Bora Cetin, PhD
Assistant Professor
Department of Civil, Construction and Environmental Engineering
Iowa State University
494 Town Engineering Building
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Office Phone: 515-294-8158
Mobile Phone: 336-686-1361
Email: bcetin@iastate.edu

Please provide the following information:

County: ______________________________
District: (if applicable) ______________________________
Name: ________________________________
Phone: _______________________________
Email: _______________________________

Are you a county engineer or a motor grader operator?

a) County Engineer
b) Motor Grader Operator

Section A. Actual Gravel Loss and Reliability

Question 1: What are the approximate total miles, average width, and average daily traffic of granular roadways in your county/district?

Table B-1. Granular roadway statistics by county

County	Total length of granular roadways (mi)	Average width of granular roadways (ft)	Average daily traffic (vpd)
Allamakee	682	26	60
Clay	736	20	25
Clayton	900	28	50
Clinton	790	24	75
Dickinson	485	20	25
Guthrie	730	26	30
Hamilton	715	26	35
Howard	610	28	50
Jefferson	521	26	45
Keokuk	721	28	50
Kossuth	1,100	22	25
Marion	650	26	125
Monroe	500	24	86
Montgomery	510	28	80
Muscatine	410	30	150
Polk	169	28	
Scott	346	28	75
Story	706	26	40
Union	505	25	40
Washington	656.5	30	75

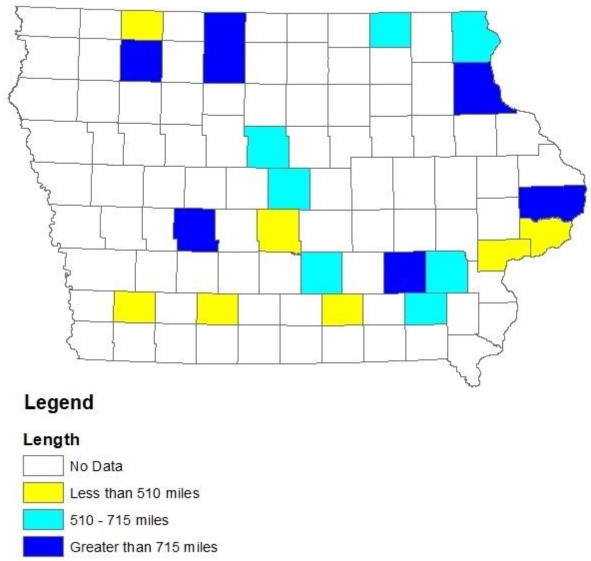

Figure B-1. Roadway system size by county

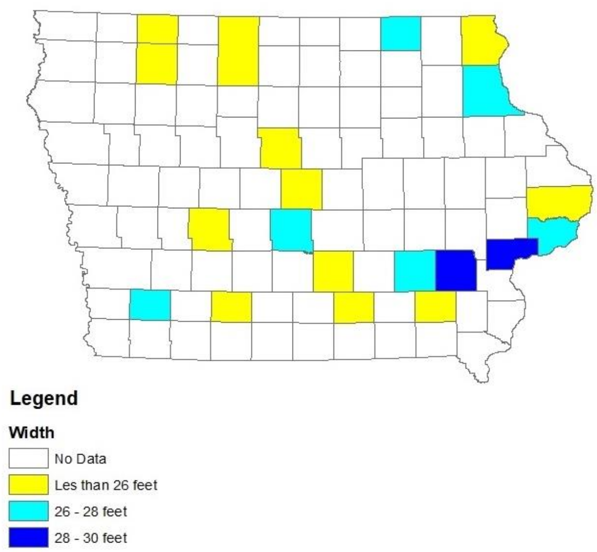

Figure B-2. Roadway width by county

Question 2: Approximately, what percentage of granular roadways in your county/district has heavy truck traffic?

Table B-2. Percentage with heavy truck traffic by county

County	Percentage of granular roadways with heavy truck traffic
Allamakee	20
Clay	90
Clayton	10
Clinton	100
Dickinson	5
Guthrie	40
Hamilton	30
Howard	100
Jefferson	15
Keokuk	10
Kossuth	100
Marion	80
Monroe	70
Montgomery	20
Muscatine	20
Polk	50
Scott	50
Story	10
Union	75
Washington	25

Question 3: Approximately, what is the percentage of truck traffic with respect to daily traffic on granular roadways in your county/district over different seasons?

Table B-3. Percentage of heavy truck traffic by season

County	Percentage of truck traffic with respect to daily traffic		
	January to April	**May to August**	**September to December**
Allamakee	15	25	20
Clay	75	15	75
Clayton	5	10	15
Clinton	33	33	33
Dickinson	10	15	20
Guthrie	15	35	50
Hamilton	35	30	60
Howard	15	15	50
Jefferson	4	8	6
Keokuk	10	10	15
Kossuth	15	15	15
Marion	5	5	5
Monroe	25	35	35
Montgomery	20	10	30
Muscatine	20	20	20
Polk	1	10	15
Scott	30	50	80
Story	8	5	10
Union	10	20	25
Washington	10	15	20

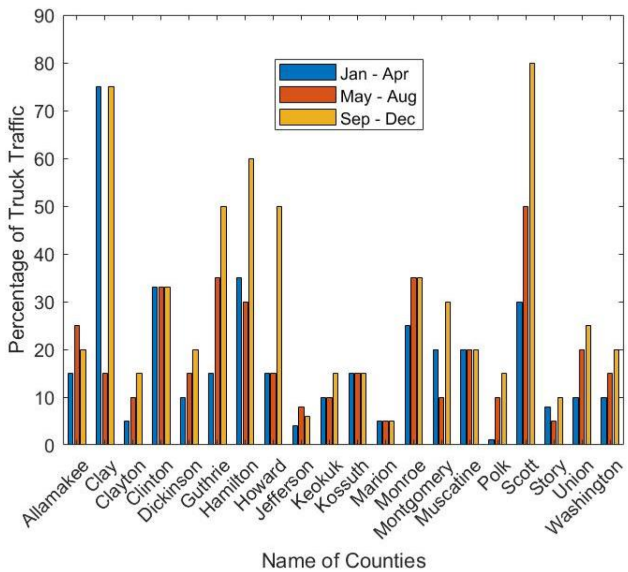

Figure B-3. Seasonal truck traffic variation

Question 4: What should be the desirable thickness for a *typical* granular roadway in your county/district to be considered in excellent condition?

Table B-4. Excellent condition thickness

County	Desired thickness (in.)
Allamakee	5
Clay	5
Clayton	4
Clinton	4
Dickinson	3
Guthrie	2
Hamilton	5
Howard	4
Jefferson	3
Keokuk	3
Kossuth	4
Marion	4
Monroe	5
Montgomery	5
Muscatine	6
Polk	5
Scott	4
Story	5
Union	4
Washington	4

Question 5: Please review the definitions of terms for overall surface condition to answer the following questions.

Table B-5. Definition of terms for overall surface condition rating

Rating	Description
Excellent	Newly constructed/maintained road. Excellent crown and drainage. No maintenance required.
Good	Good crown and drainage. Routine maintenance required.
Fair	Roadway shows deteriorating effects from traffic. Regrading, spot rocking, minor ditch maintenance required.
Poor	Road needs resurfacing, major drainage maintenance works.
Unacceptable	Complete rebuilding required.

Now, for a *typical* granular road in your county/district, if it were to start from an excellent condition, by how much would the thickness decrease over the years if no maintenance/repair such as spot rocking or resurfacing activities were performed?

Table B-6. Typical roadway degradation per year by county

	Decrease in roadway thickness (in.) after						
County	**1 Year**	**2 Years**	**3 Years**	**4 Years**	**5 Years**	**6 Years**	**7 Years**
Allamakee	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Clay	2.00	3.00	3.00				
Clayton	1.00	1.00	1.00	1.00	1.00		
Clinton	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Dickinson		1.00		1.00		1.00	
Guthrie	0.25	0.25	0.25	0.25	0.50	0.50	
Hamilton	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Howard							
Jefferson	0.40	0.50	0.50	0.70	0.80	1.00	1.00
Keokuk	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Kossuth							
Marion	0.75	,75	1.25	1.25			
Monroe	0.50	0.50	1.00	1.00	1.00	1.00	1.00
Montgomery	1.00	1.00	1.00	1.00	1.00		
Muscatine	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Polk	1.00	1.00	1.00	1.00	1.00		
Scott	1.00	1.00	1.00				
Story	1.00	0.50	0.50	0.50	0.50	0.50	0.50
Union	0.20	0.20	0.20	0.20	0.30	0.40	0.50
Washington	0.50	0.50	0.75	0.75	1.00	0.50	

Question 6: If all granular roads in your county/district started from an excellent condition, what percentage would be in unacceptable condition if no maintenance/repair activities such as spot rocking or resurfacing were conducted for the following durations?

Table B-7. Percentage expected to be in unacceptable condition if no resurfacing or spot rocking conducted per year by county

County	1 year	2 years	3 years	4 years	5 years	6 years	7 years
Allamakee	3	7	11	18	28	45	63
Clay		50	75	95	100		
Clayton	0	5	10	50	60	70	80
Clinton	10	30	80	100			
Dickinson	5	10	25	40	100		
Guthrie	10	20	30	50	60	60	60
Hamilton	5	10	20	30	40	55	70
Howard	5	25	50	75	100		
Jefferson	20	40	60	80	100	100	100
Keokuk	33	67	100				
Kossuth	0	25	50	75	100	100	100
Marion	30	60	100				
Monroe	1	5	15	40	60	70	80
Montgomery	10	50	90	95	100		
Muscatine	20	40	60	70	80	85	90
Polk	20	35	50	75	100		
Scott	10	25	40	60			
Story		7	15	20	40	60	80
Union	0	2	5	10	20	40	60
Washington	5	10	30	50	65	75	90

Question 7: After reviewing the definitions of terms for overall surface condition rating in Question 5, for a *typical* year, please estimate the percentage of granular roads in your county/district that are in each condition.

Table B-8. Percentage of granular roads per condition by county

County	Excellent	Good	Fair	Poor	Unacceptable
Allamakee	25	50	17	7	1
Clay	15	50	20	10	
Clayton	0	5	60	30	5
Clinton	10	40	40	10	
Dickinson	2	40	40	18	2
Guthrie	10	30	45	10	5
Hamilton	1	20	55	20	4
Howard	5	30	30	30	5
Jefferson	3	20	65	10	2
Keokuk	5	30	50	10	5
Kossuth	25	50	25	0	0
Marion	5	25	60	10	
Monroe	3	15	77	4	1
Montgomery	5	25	30	20	15
Muscatine	30	50	15	5	0
Polk	65	20	14	1	
Scott	30	30	20	10	
Story	15	25	40	15	5
Union	5	20	70	5	0
Washington	10	30	30	25	5

Question 8: Please estimate the percentage of granular roads within each category that get resurfaced or spot rocked in a *typical* year.

Table B-9. Percentage of granular roads per condition that get resurfaced/spot rocked in typical year by county

County	Excellent	Good	Fair	Poor	Unacceptable
Allamakee	33	40	20	3	3
Clay	35	55	5	5	
Clayton	0		20	10	5
Clinton	100	50	10		
Dickinson	90	80	80	80	80
Guthrie	10	35	75	90	100
Hamilton	0	10	50	35	5
Howard	50	50	75	75	100
Jefferson	0	5	50	100	100
Keokuk	33	33	33	33	33
Kossuth	0	25	50		
Marion	100	100	33	33	
Monroe	1	5	35	80	95
Montgomery	2	30	75	90	100
Muscatine	10	50	50	80	0
Polk		100	100	100	
Scott	0	5	30	5	
Story	10	20	60	80	80
Union	0	0	70	80	0
Washington	20	25	75	75	100

Question 9: Based on your experience and judgement, what is the minimum thickness of gravel before any resurfacing job must be performed? 1 inch, 2 inches, or Other (please specify)

Table B-10. Minimum gravel thickness before any resurfacing job by county

County	Minimum thickness (in.)
Allamakee	2
Clay	2
Clayton	2
Clinton	2
Dickinson	2
Guthrie	
Hamilton	2
Howard	1
Jefferson	2
Keokuk	1
Kossuth	2
Marion	1
Monroe	1
Montgomery	2
Muscatine	
Polk	
Scott	1
Story	2
Union	2
Washington	2

Section B. Surface Condition

Question 10: After reviewing the attached Surface Condition Rating Report, please provide a threshold score for each of the distress columns that will trigger you to do resurfacing work.

Table B-11. Threshold score that will trigger resurfacing work by county

County	Rutting	Washboarding	Potholes	Loose aggregates	Dust	Crown	Drainage
Allamakee	4	4	4	4	3	5	4
Clay	6	4	6	4		2	2
Clayton	7	7	7	6	NA	NA	NA
Clinton	7	6	5	6	3	4	3
Dickinson							
Guthrie	6	NA	NA	NA	NA	NA	NA
Hamilton	4	3	5	1	2	2	3
Howard							
Jefferson	4	4	4	2	1	1	3
Keokuk	4	6	6	6	2	4	3
Kossuth	5	4	5	4	1	2	4
Marion	6	4	4	2			
Monroe	6	2	3	8	4	1	2
Montgomery	6	4	6	9	0	2	4
Muscatine	6	6	6	3	3	5	6
Polk	4	5	6	6	1	1	3
Scott	4	5	5	3	1	1	3
Story						1	
Union	5	0	5	0	0	2	3
Washington	6	6	7	7	3	2	3

Question 11: After reviewing the attached Surface Condition Rating Report, please provide an approximate score for each of the distress columns that represent the *typical* granular roadway in your county/district in a *typical* year.

Table B-12. Approximate score for typical granular roadway in a typical year by county

County	Rutting	Washboarding	Potholes	Loose aggregates	Dust	Crown	Drainage
Allamakee	6	5	7	5	3	7	5
Clay	6	6	8	7	2	2	1
Clayton	7	7	7	6	2	2	4
Clinton	7	7	6	6	3	5	4
Dickinson							
Guthrie	7	6	8	6	3	3	4
Hamilton	6	7	7	6	3	3	3
Howard							
Jefferson	7	7	7	4	2	2	4
Keokuk	7	8	7	7	3	3	3
Kossuth	7	7	7	7	7	5	4
Marion							
Monroe	6	6	7	6	2	2	3
Montgomery	7	9	7	7	1	2	5
Muscatine	7	7	6	6	6	7	6
Polk	7	7	9	7	2	4	5
Scott	8	7	6	5	2	2	4
Story	5	1	2	6	7	4	3
Union	7	8	6	8	3	3	4
Washington	8	8	8	8	1	2	4

Question 12: Which specification do you currently follow to select surfacing material?

Table B-13. Approximate score for typical granular roadway in a typical year by county

County	Aggregate/Rock material properties
Allamakee	Iowa DOT Class A Gravel
Clay	Clay County owns Gravel Pits. We have a contractor crush the material and use it on our roads
Clayton	Iowa DOT Class A Gravel
Clinton	Own Modified B
Dickinson	Combination of Iowa DOT Class C and D
Guthrie	(1" 80–100%) (#4 50–68%) (#8 35–55%) (#200 0–10%)
Hamilton	Class D and E
Howard	Iowa DOT Class A Gravel
Jefferson	Iowa DOT Modified Subbase (limestone) Gradation 14; sometimes 1" Clean (limestone)
Keokuk	Class D (Similar to Iowa DOT Class A)
Kossuth	Kossuth County owns Gravel Pits. We have a contractor crush the material and use it on our roads
Marion	Abrasion: 45 percent max. allowed (AASHTO T 96) C Freeze: 15 percent max. allowed (Iowa DOT Office of Materials test Method No. 211, Method C) Chert: 2 percent max. allowed (per Mat. IM 372 and retained on No. 4 sieve and above) 0.75 inches Road Stone Sieve
Monroe	Iowa DOT Class A Gravel
Montgomery	Local Spec “C” with less fines
Muscatine	Iowa DOT Class A Gravel
Polk	Cl A Crushed Stone, 1", Iowa DOT Grad. No. 11, except 100% passing 1-1/2" sieve
Scott	County Class D
Story	Iowa DOT Class A Gravel and Class D
Union	Class D 1.5" minus gradation. See properties from DOT test reports for Schildberg’s Thayer Quarry
Washington	Iowa DOT Class A and D

Note: These are actual responses from survey respondents

Question 13: On a scale of 1 to 9, with 1 being least influential and 9 being most influential, please rate each of the following factors influencing the deterioration of granular roads in your county/district: Truck Traffic, Aggregate/Material/Rock Quality, Frost Boils, Freeze Thaw Action, Subgrade Quality, Other (please describe and rate, i.e., Farm Equipment)

Table B-14. Rating (1–9) of factors influencing deterioration by county

County	Truck traffic	Aggregate quality	Frost boils	Freeze thaw action	Subgrade quality	Rainfall	Others	Notes
Allamakee	7	9	4	5	7	3	6	Springtime manure tankers
Clay	9	6	4	4	4	9	9	Farm equipment
Clayton	9	6	3	4	7	5	8	Farm equipment
Clinton	7	7	6	6	7	6	5	Loss of aggregate
Dickinson	9	6	6	8	9	9		Windmill loading, manure wagon, spring thaw loading, extreme dry, prolong wet during freeze thaw
Guthrie	8	7	4	8	3	5	8	Ag places the heaviest burden, especially operations that require action in all weather conditions
Hamilton	5	7	7	6	8	6	9	Slope, crown, shoulder, ditch
Howard	7	1	5	3	7		7	Farm equipment
Jefferson	5	8	2	4	6	5	6	Farm equipment
Keokuk	5	7	4	6	7	9		Super load, during freeze-thaw and wet
Kossuth	7	3	7	7	7	4		
Marion								Traffic volume in general
Monroe	7	8	6	9	9	7	8	Farm equipment
Montgomery	6	9	7	7	5	5	8	Heavy grain loads
Muscatine	9	7	5	6	8	5	7	Large ag equipment
Polk	6	4	3	3	4	8		
Scott	7	4	3	3	5	3		
Story	6	7	9	8	5	5		
Union	9	8	3	7	7	9	9	Animal confinements (truck traffic destinations)
Washington	9	7	7	7	4	4	9,7,9	Ag traffic, car traffic, traffic volume

Notes are actual responses from survey respondents

APPENDIX C. ROADWAY SURFACE CONDITION RATING REPORT

Surface Condition Rating Report for a typical year in your county/district for IHRB Project TR-729: Development of Granular Roads Asset Management System (GRAMS)

Score	Rutting	Washboarding	Potholes	Loose aggregate	Dust	Crown	**Drainage** (based on time required for 50% of drainable water to be removed)
9	No or negligible ruts	No or negligible corrugations	No or negligible potholes	No or negligible loose aggregate;			
8	Ruts less than 1" deep and less than 5% of the roadway surface	Less than 1" deep; less than 10% of roadway surface area	Most small potholes less than 1" deep and less than 1' diameter	Berms <1" deep; Loose aggregate. <3/4" thick			
7							
6	Ruts between 1"-3" deep and 5% to 15% of the roadway surface	1"-2" deep;10%-25% of roadway	Considerable potholes less than 3" deep and less than 2' diameter	Berms <2" deep; Loose aggregate <1.5" thick			
5							Excellent: 2 hours
4	Ruts between 3"-6" deep and 10% to 40% of the roadway surface	2"-3" deep; over 25% of roadway	Many potholes up to 4" deep and 3' in diameter	Berms between 2"-4" deep;	No visible dust		Good: 1 Day
3					Minor dust and no visible obstruction	Cross slope >3%; good rooftop shape	Fair: 1 Week
2	Ruts between 6"-12" deep	Deeper than 3”; over 30% of roadway	Up to 8" deep and > 4' in diameter	Berms >4" deep	Significant dust; Dust loss is major concern	1% to 3%	Poor: 1 Month
1	Ruts over 12" deep	Impassable	Impassable	Sand dunes	Heavy dust and obscures vision	<1%	Very poor: water will not drain

Date: **County:** **District:** **Roadway System Thickness (inches):**

APPENDIX D. SUMMARY OF HISTORICAL DATA

Table D-1. Precipitation rate, traffic, and soil quality by county

County	Precipitation rate (in./hr)	Traffic (AADT)	Soil quality
Adair	0.005030982	47	1.18
Adams	0.005143169	32	1.22
Allamakee	0.00517	55	1.58
Appanoose	0.005351678	52	1.3
Audubon	0.004868461	37	1.15
Benton	0.004910794	63	1.52
Black Hawk	0.004979234	101	1.91
Boone	0.005197026	45	1.63
Bremer	0.00510032	59	1.64
Buchanan	0.00494739	66	1.85
Buena Vista	0.004600752	39	1.95
Butler	0.004869151	45	1.78
Calhoun	0.004701871	34	2
Carroll	0.004789934	50	1.75
Cass	0.004868461	38	1.25
Cedar	0.005172851	62	1.45
Cerro Gordo	0.004869151	54	1.91
Cherokee	0.004437567	37	1.73
Chickasaw	0.00506223	55	2.04
Clark	0.005173482	96	1.16
Clay	0.004477924	54	1.77
Clayton	0.005086805	59	1.65
Clinton	0.005114403	57	1.57
Crawford	0.004651938	46	1.87
Dallas	0.005030982	102	1.9
Davis	0.005351678	55	1.23
Decatur	0.00520872	45	1.31
Delaware	0.004997558	59	1.85
Des Moines	0.005412497	86	1.41
Dickinson	0.004639864	46	1.75
Dubuque	0.005106151	95	1.63
Emmet	0.004639864	31	1.97
Fayette	0.00510032	49	1.51
Floyd	0.00506223	49	2.07
Franklin	0.004869151	39	1.42
Fremont	0.004497703	44	1.55
Greene	0.004974451	32	2.09
Grundy	0.004979234	46	1.75

County	Precipitation rate (in./hr)	Traffic (AADT)	Soil quality
Guthrie	0.005030982	41	1.72
Hamilton	0.004821004	40	2.04
Hancock	0.004780779	38	1.97
Hardin	0.005013203	46	1.84
Harrison	0.004743415	46	1.54
Henry	0.005275652	69	1.45
Howard	0.005184885	53	1.97
Humboldt	0.004641711	31	1.97
Ida	0.004437567	33	1.41
Iowa	0.005148507	60	1.4
Jackson	0.005114403	69	1.6
Jasper	0.005181463	71	1.34
Jefferson	0.005275652	52	1.3
Johnson	0.005127404	93	1.73
Jones	0.005022164	60	1.86
Keokuk	0.005127404	44	1.2
Kossuth	0.004641711	31	2.05
Lee	0.005335979	84	1.2
Linn	0.005022164	120	1.87
Louisa	0.005412497	64	1.66
Lucas	0.005059019	52	1.17
Lyon	0.004172968	38	1.53
Madison	0.00520997	67	1.48
Mahaska	0.005148507	54	1.46
Marion	0.005181463	68	1.11
Marshall	0.00526292	81	1.61
Mills	0.004497703	64	1.34
Mitchel	0.005184885	51	1.91
Monona	0.004651938	41	1.25
Monroe	0.005059019	56	1.17
Montgomery	0.004497703	44	1.11
Muscatine	0.005172851	68	1.35
Obrien	0.004477924	37	1.51
Osceola	0.004484686	34	1.88
Page	0.004773513	37	1.05
Palo Alto	0.004600752	39	1.63
Plymouth	0.004249801	50	1.62
Pocahontas	0.004600752	30	1.97
Polk	0.00520997	1,139	1.81
Pottawattamie	0.004497703	67	1.26
Poweshiek	0.005148507	44	1.22
Ringgold	0.005118166	41	1.24

County	Precipitation rate (in./hr)	Traffic (AADT)	Soil quality
Sac	0.004615086	35	1.38
Scott	0.00527058	132	1.74
Shelby	0.004789934	43	1.37
Sioux	0.004249801	67	1.69
Story	0.005197026	89	2.2
Tama	0.005006259	52	1.51
Taylor	0.005118166	36	1.03
Union	0.005143169	51	1.09
Van Buren	0.005384499	45	1.35
Wapello	0.00506116	78	1.2
Warren	0.00520997	110	1.08
Washington	0.005127404	59	1.41
Wayne	0.00533447	38	1.36
Webster	0.004701871	44	1.65
Winnebago	0.004972964	38	1.96
Winneshiek	0.00515122	68	1.47
Woodbury	0.004269914	72	1.99
Worth	0.005020871	32	1.68
Wright	0.004780779	37	2.19

Table D-2. Los Angeles abrasion and fines by county

County	Los Angeles abrasion (%)	Fines (%)
Appanoose		4
Davis		6.5
Des Moines		8
Henry		9
Henry		7.5
Henry	44	
Jefferson		8
Lee		7
Linn	33	10
Marion		4.5
Monroe		5
Monroe		5
Union		5.6
Van Buren		6.5
Wapello		6.5
Iowa		7.5
Keokuk		6.5
Keokuk	48	
Mahaska		6
Poweshiek		
Ringgold	32	
Washington		7.5
Washington		11
Washington		11
Guthrie		5
Hardin	41	7
Montgomery	33	9.9
Polk	25	
Shelby	27	9.7
Hamilton	37	8
Pocahontas	29	10
Webster	34	8

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