Paved Shoulders on Primary Highways in Iowa:
An Analysis of Shoulder Surfacing Criteria, Costs, and Benefits

Final Report

Sponsored by the Office of Traffic and Safety
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ABSTRACT

The value of providing paved shoulders adjacent to many higher volume roadways has been accepted in many states across the country. Iowa's paved shoulder policy is considerably more conservative than neighboring states, particularly on rural four-lane and high-volume two-lane highways.

The objectives of this research are to examine current design criteria for shoulders employed in Iowa and surrounding states, compare benefits and costs of alternative surface types and widths, and make recommendations based on this analysis for consideration in future design policies for primary highway in Iowa.

The report finds that many safety and maintenance benefits would result from enhancing Iowa's paved shoulder and rumble strip design practices for freeways, expressways, and Super 2 highway corridors. The benefits of paved shoulders include reduced numbers of certain crashes, higher capacity potentials, reduced maintenance, enhanced opportunities for other users such as bicyclists, and even possible increased longevity of pavements. Alternative paved shoulder policies and programming strategies are also offered, with detailed assessments of the benefits, costs, and budget impacts.

PAVED SHOULDERS ON PRIMARY HIGHWAYS IN IOWA:
AN ANALYSIS OF SHOULDER SURFACING CRITERIA, COSTS, AND BENEFITS

FINAL REPORT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY[1]

Background

Almost 50 percent of rural fatal crashes in the United States occur on tangent alignments and level roads away from intersections. Single-vehicle run-off-the-road crashes are the highest crash type in rural areas nationally. Fatigue, drowsiness, and distracted driving are major contributing factors to single-vehicle run-off-the-road crashes. These types of rural accidents appear to be rising with an increase in inattentive driving and more long-distance commercial travel.

The scope and seriousness of this type of crash is very significant. The estimated annual cost of run-off-the-road crashes in the United States is $80 billion. In addition to these costs, there are the hidden costs of emotional distress and family disruptions.

In Iowa, approximately 25 percent of all fatal crashes involve a single vehicle that runs off the road and fails to recover. Four of Iowa's 15 fatal accidents (5 of 15 fatalities) reported for the week ending July 13, 2001, had the following notes:

- "drop off pavement, overturned in ditch" (age 63)
- "drop off pavement, lost control, overturned" (age 43)
- "car drop off pavement, over corrected, head-on into semi" (ages 99 and 75)
- "drop onto shoulder, lost control, overturned" (age 70)

Even more recently, on the morning of September 16, 2001, a 1988 Chevrolet S-10 was traveling south on IA 330 southwest of Marshalltown when the driver steered onto the granular shoulder, and lost control when trying to recover. The vehicle spun into the northbound lane, where it was struck by a 1998 Buick Park Avenue and then by a 1990 Chevrolet van. Four fatalities occurred immediately as a result of the impacts, and another passenger died later. This crash is still under investigation.

The Iowa State Patrol fatal crash investigation officers report that deficient granular shoulders are a major contributing factor to many of Iowa's fatal crashes. A very significant number of past highway crash tort claims in Iowa were related to the maintenance of our granular shoulders.

The above information explains why a recent survey (conducted by the University of Northern Iowa Center for Social and Behavior Research) found that 66 percent of Iowans surveyed supported providing paved shoulders with rumble strips on Iowa highways.

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[1] Much of this Executive Summary was authored by Tom Welch, State Traffic Safety Engineer, Iowa DOT Office of Traffic and Safety. As such, the recommendations presented in the Executive Summary are those of the Iowa DOT but are not necessarily identical to those presented in the body of the report. The recommendations in the report are based on the findings of the investigation by the Center for Transportation Research and Education (CTRE). This in no way indicates disagreement on conclusions.

The American Association of State Highway and Transportation Officials *AASHTO Strategic Safety Plan* identifies reducing run-off-the-road crashes as a high-priority emphasis area in the effort to achieve a significant reduction in highway crashes. The Iowa Safety Management System (Iowa SMS) Coordination Committee has also listed this as a priority emphasis area. Identifying high-crash horizontal curves and a review of the Iowa Department of Transportation (Iowa DOT) paved shoulder policy on rural multi-lane and Super 2 highways are two strategies in the Iowa SMS *Toolbox of Highway Safety Strategies*.

The Iowa DOT has recently revised its paved shoulder policy for National Highway System (NHS) roads to provide a two-foot paved shoulder on new two-lane construction and 3R projects. Iowa rural freeways and expressways provide for a two-foot paved right shoulder but no paved shoulder on the left side. However, if the average daily traffic (ADT) is greater than 10,000 vehicles per day (vpd), full-width paved shoulders are considered.

Study Scope

Iowa's paved shoulder and rumble strip policy is considerably more conservative than neighboring states, particularly on rural four-lane and high-volume two-lane highways. A study committee was formed at the Iowa DOT to review the costs and benefits of providing wider paved shoulders and rumble strips along Iowa's non-interstate freeways, expressways, and Super 2 highway corridors.

The Center for Transportation Research and Education at Iowa State University was retained to review past related research, survey neighboring states on their paved shoulder policies, and develop crash data on Iowa freeways and expressways. The CTRE research was done in conjunction with the *Systematic Identification of High Crash Locations* project (TR-442) sponsored by the Iowa Highway Research Board and Iowa DOT.

The results of these collaborative efforts are documented in this report. The report discusses the maintenance and safety benefits and program impacts of enhancing Iowa's paved shoulder policy. Alternative paved shoulder policies and programming strategies are also discussed.

Research Findings

National Studies

There is considerable evidence, from numerous research studies, that high-volume two-lane and four-lane rural highways with paved shoulders are much safer than similar roadways without paved shoulders. For example, a Minnesota Department of Transportation study found that two-lane rural roadways with paved shoulders at least four feet wide reduced single vehicle and total crashes by up to 15 percent. An Australian study found that roads with paved shoulders had fatal crash rates 60–70 percent less than roads without paved shoulders.

Paved shoulders provide the opportunity to install shoulder rumble strips, which further enhance motorist safety. Research reports indicate that the installation of shoulder rumble strips can additionally reduce run-off-the-road crashes by 20–50 percent.

A survey of state departments of transportation identified studies that determined shoulder rumble strip installation projects had a benefit/cost ratio between 30:1 and 60:1. Rumble strips also proved more cost effective than other safety improvements such as guardrails, culvert end treatments, and slope flattening.

Previous research indicates that partially paved shoulders become cost effective on rural two-lane roadways if traffic volumes are in excess of 1,500–2,000 vpd. Full-width paved shoulders are generally not cost effective on roads carrying less than 3,000 vpd.

Iowa Studies

The 1996–1999 crash data on Iowa's rural freeways were reviewed as part of the 2001 *Speed Study Report* to the Iowa Legislature. The interstate system has paved shoulders, and many miles of the interstate have shoulder rumble strips as well. For the most part non-interstate freeways in Iowa do not have paved shoulders. Other than this difference, these highway classes have similar design standards. Table ES.1 reflects the difference in crash rates on these rural freeways with (interstate) and without (non-interstate) paved shoulders. Both the total crash rate and the fatal crash rate are 50 percent less on Iowa freeways that have full-width paved shoulders. Much of this difference can be attributed to full-width paved shoulders and rumble strips.

Table ES.1. Crash Rates for Rural Non-interstate and Interstate Freeways in Iowa

	Number of Miles	Total Crash Rate*	Fatal Crash Rate*
Rural non-interstate freeways	126	103	1.18
Rural interstate freeways	654	53	0.57

*Per hundred million vehicle miles of travel.

The 1995 Iowa DOT Paved Shoulder Task Force determined that providing a three-foot-wide full-depth paved shoulder became cost effective on roadways with an ADT in excess of 2,100. This analysis included both safety and maintenance benefits.

Paved Shoulder Practices in Neighboring States

Table ES.2 provides a summary of the paved shoulder practices for Iowa and neighboring states. Each of the states provide an 8 to 10 foot wide paved right shoulder on four-lane rural highways and, for the most part, a 6 to 8 foot wide paved shoulder on high-volume two-lane highways.

Alternative Paved Shoulder Policies

The Iowa DOT paved shoulder policy is considerably more conservative than those of neighboring states (see Table ES.2 for comparisons). However, it is not fiscally prudent to implement further enhancements to our paved shoulder policy on our *entire* roadway system at this time.

If changes to the paved shoulder policy are implemented, the initial enhancements are recommended to focus on the high-volume roadways (freeway, expressway, and Super 2 highway corridors) where the safety and maintenance benefits would be maximized.

Table ES.2. Paved Shoulder Practices in Iowa and Neighboring States

<table>
<tr><th rowspan="2">State</th><th colspan="2">Total Shoulder Width/Shoulder Width Paved</th><th rowspan="2">Miscellaneous</th></tr>
<tr><th>Rural Multi-Lane Highways</th><th>Two-Lane Highways</th></tr>
<tr><td>Iowa</td><td>Right 10 ft/2 ft
Left 6 ft/0 ft
Greater than 10,000 ADT consider full-width paved shoulder</td><td>NHS 10 ft/2 ft
Non NHS:
ADT > 2000 10 ft/2 ft
ADT < 2000 8 ft/2 ft</td><td>2-ft paved shoulder on 3R projects
Rumble strips on full-width paved shoulders and 2-ft portland cement concrete (PCC) shoulders</td></tr>
<tr><td>Illinois</td><td>Right 10–12 ft/8–12 ft
Left 6 ft/4–6 ft</td><td>Principal arterial 10 ft/10 ft
Minor arterial 10 ft/4 ft</td><td>3R improvements:
3-ft paved shoulder if ADT > 3,000
1–2 ft paved shoulder if ADT < 3,000
Rumble strips on freeways and expressways or high accident locations</td></tr>
<tr><td>Minnesota</td><td>Right 11.5 ft/10 ft
Left 5.5–11.5 ft/4–10 ft</td><td>ADT > 2,000 9.5–11.5 ft/8–10 ft
ADT < 2,000 4–8 ft/1.5 ft min</td><td>Min 4-ft paved shoulder if bike usage anticipated
Rumble strips on paved shoulders greater than 4 ft</td></tr>
<tr><td>Wisconsin</td><td>Right 10 ft/8–10 ft
Left 6–10 ft/3–10 ft</td><td>ADT > 1,250 6–10 ft/3 ft min</td><td>Min 5-ft paved shoulder if bike ADT > 25 bicycles per day
Rumble strips on most paved shoulders</td></tr>
<tr><td>South Dakota</td><td>Right 8/8 ft
Left 4/4 ft</td><td>ADT > 2,500 8/8 ft
ADT < 2,500 28-ft pavement</td><td>Rumble strips on all paved shoulders</td></tr>
<tr><td>Nebraska</td><td>Right 10 ft/8 ft
Left 6 ft/4 ft</td><td>Priority System 10 ft/8 ft
ADT > 3000 8 ft/8 ft
ADT < 3,000 28 ft pavement</td><td>Rumble strips on all paved shoulders located to facilitate bikes</td></tr>
<tr><td>Missouri</td><td>Right 10 ft/10 ft
Left 4 ft/4 ft</td><td>ADT > 3,500 variable-width paved shoulder</td><td>Rumble strips provided on all paved shoulders</td></tr>
</table>

Three alternative paved shoulder policy enhancements were evaluated. The first alternative would provide for paved shoulders on freeway, expressway, and Super 2 corridors comparable to the practices of neighboring states. The second and third alternatives would enhance the paved shoulder practices on freeways, expressways, and Super 2 corridors to a level between our current standards and those of neighboring states. All proposed standards and cost estimates are based on a “full depth” eight-inch-thick asphalt cement concrete (ACC) paved shoulder. See Table ES.3 for details.

Table ES.3. Alternative Paved Shoulder Width Standards

<table>
<tr><th rowspan="3"></th><th colspan="3">Total Shoulder Width/Shoulder Width Paved</th></tr>
<tr><th colspan="2">Freeway/Expressway</th><th rowspan="2">Super 2</th></tr>
<tr><th>Right</th><th>Left</th></tr>
<tr><td>Alternative 1</td><td>10 ft/10 ft</td><td>6 ft/6 ft</td><td>10 ft/10 ft</td></tr>
<tr><td>Alternative 2</td><td>10 ft/6 ft</td><td>6 ft/6 ft</td><td>10 ft/6 ft</td></tr>
<tr><td>Alternative 3</td><td>10 ft/4 ft</td><td>6 ft/2 ft</td><td>10 ft/4 ft</td></tr>
<tr><td>Existing</td><td>10 ft/2 ft</td><td>6 ft/0 ft</td><td>10 ft/2 ft</td></tr>
</table>

Cost Assessment

Table ES.4 reflects the estimated per-mile construction costs for the alternative paved shoulder standards.

Table ES.4. Estimated Construction Costs for Alternatives

	Estimated Construction Cost (per mile)			
	Current	**Alternative 1**	**Alternative 2**	**Alternative 3**
New expressway, four lane	$3,000,000	$3,187,000	$3,134,000	$3,054,000
3R for expressways, four lane	$400,000	$650,000	$580,000	$470,000
Reconstructed Super 2	$2,000,000	$2,107,000	$2,054,000	$2,027,000

There are 91 miles of non-interstate freeways/expressways with paved shoulders. Excluding the interstate system, there are approximately 500 miles of freeways and expressways with granular shoulders in Iowa. The long-term budget impact, based on today's costs to replace these granular shoulders with paved shoulders, is estimated in Table ES.5.

Table ES.5. Cost to Replace Granular Shoulders on Existing Freeway/Expressway System

	Cost
Alternative 1	$125,000,000
Alternative 2	$90,000,000
Alternative 3	$36,000,000

It is estimated that paved shoulders would reduce maintenance costs by about $7,000 per mile over a 20-year period. However, an additional cost of between $9,000 and $37,000 per roadway mile would be required to resurface the paved shoulders in the future, depending on width.

Recommendations

1. Adopt a goal to have new paved shoulder standards fully implemented on existing and proposed freeway/expressways and Super 2 corridors within 20 years.

2. Phase in the new standards on freeway and expressway initial construction and 3R projects as funding becomes available in the current five-year program or beginning in FY 2006.

3. Consider applying new standards to all two-lane corridors with a design ADT in excess of 3,500 vpd.

4. Provide funding (two million dollars/year) to pave shoulders on existing freeways/expressways that have above-average crash rates and that are not programmed to be resurfaced within 10 years.

5. Provide funding to install shoulder rumble strips on selected existing freeways and expressways that do not currently have rumble strips.

6. The design and placement of rumble strips on expressways and Super 2 roadways should safely accommodate bicyclists.

7. For primary routes that warrant bicycle accommodations, including but not limited to sections designated as part of Iowa's Vision Corridors, a six-foot-wide paved shoulder should be considered.

8. A new paved shoulder standard similar to Alternative 2 would be the most cost effective improvement alternative. The study committee recommends that consideration be given to providing a six-foot paved shoulder, with milled in rumble strips, on both sides of all freeways, expressways, Super 2 corridors and two-lane roadways with ADTs greater than 3,500 vpd. The current 28 foot width pavement standard would apply to two lane roadways with traffic volumes less than 3,500 vpd.

INTRODUCTION

Background

Shoulders have been defined by the American Association of State Highway and Transportation Officials (AASHTO) as "The portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles, for emergency use, and for lateral support of the base and surface courses." However, the function of shoulders, especially adjacent to pavements, has expanded in recent years to include such features as expediting surface runoff from the roadway, providing safe space for maintenance and construction activities, accommodating use by slow-moving equipment and bicycles, and adding an important safety feature for drivers who unintentionally steer from the traffic lanes. The *AASHTO Strategic Safety Plan* (*1*) identifies reducing run-off-the-road crashes as a high-priority emphasis area in the effort to achieve a significant reduction in highway crashes.

Recognizing the importance of high-quality shoulders, most states have adopted policies that guide the design and maintenance of these roadway features. The Iowa Department of Transportation (Iowa DOT) also follows carefully developed guidelines for shoulders adjacent to primary highways. These standards are based on road classification, traffic volume, category of improvement anticipated, and other miscellaneous factors. However, Iowa's paved shoulder policy is considerably more conservative than those of its neighboring states.

Study Description

The objectives of this research are to examine current design criteria for shoulders employed in Iowa and surrounding states, compare benefits and costs of alternative surface types and widths, and make recommendations based on this analysis for consideration in future design policies for primary highways in Iowa.

A study committee was formed at the Iowa DOT to review the safety and maintenance benefits of providing wider paved shoulders along Iowa's non-interstate freeways, expressways, and Super 2 highway corridors. Committee members included the following:

- Stu Anderson, Systems Planning, Iowa DOT
- John Hey, Systems Planning, Iowa DOT
- Tom Welch, Traffic and Safety, Iowa DOT
- Will Zitterich, Maintenance, Iowa DOT

The Center for Transportation Research and Education (CTRE) at Iowa State University was retained to review past related research, survey neighboring states on their paved shoulder policies, and develop crash data on Iowa freeways and expressways. The CTRE research was done in conjunction with the *Systematic Identification of High Crash Locations* project (TR-442) sponsored by the Iowa Highway Research Board and Iowa DOT.

Major elements of this investigation include the following:

1. Literature review of past pertinent research and other states' practices.
2. Compilation of shoulder types on several classes of roadway including freeways (excluding interstates), expressways, and Super 2 candidate corridors.
3. Crash analysis on these roadway sections, concentrating on crash type that could be affected by shoulder surface.
4. Analysis of shoulder surface type considering factors of initial cost, maintenance, and potential safety benefits.
5. Consideration of other impacts such as use by bicycles, farm and slow-moving equipment, and wide loads.
6. Recommendations based on research data and analysis for consideration in future modification of Iowa DOT shoulder surface design guidelines for certain primary corridors and classifications.

LITERATURE REVIEW

A considerable volume of research has been accomplished in the past on shoulders, the beneficial impacts, design criteria, and maintenance cost comparisons. In addition, many studies have been undertaken of the value of paved shoulders, but many have become dated and others may not relate to conditions and circumstances in Iowa. However, several excellent research efforts were identified that provide pertinent information applicable in this state. The literature review results are described on the following pages (followed by a tabular summary, Table 1).

Shoulder Surface Type

In 1974 the American Society of Civil Engineers (ASCE) (*2*) studied accident (crash) experience on rural primary highway sections similar in every way except for shoulder surface type. This study found a generally lower crash rate with paved shoulders. The report also developed cost effectiveness curves considering these data and initial construction costs. Potential reduced maintenance was not included in the analysis. It was concluded that three to four foot minimum width paved shoulders are cost effective for rural two-lane roads with traffic volumes greater than 2,000–3,000 vehicles per day (vpd).

Two Australian studies also documented the potential benefits of paved shoulders. In 1977 (*3*) it was found that low-cost paving of shoulders, 24–28 inches in width, significantly reduced the fatality accident rates on rural two-lane roads. In 1984 (*4*) research again determined three to four times lower crash rates on roads with sealed (paved) shoulders versus those with granular shoulders, even with variable geometrics. Loss of control on granular shoulders was found to be a contributing cause in approximately 17 percent of fatal crashes.

A comprehensive international review was conducted in Australia in 1996 (*5*) to examine the potential beneficial effects of many roadway features, including shoulder surface type. The study included practices and results from Europe, Australia, and North America. This review concluded that sealed (paved) shoulders are much safer than unpaved on rural roads in general, with a significant reduction in crash rates observed. In addition, this observation holds true even with quite low traffic volumes.

A survey conducted as part of a 1993 study in Virginia (*6*) found the 32 of 35 responding states use paved shoulders on two-lane roads to some degree, with minimum widths of two feet specified in 21 of those states. Benefits of paved shoulders determined from these survey results indicated increased lateral support to the pavement, reduced maintenance costs, operational improvements, and safety considerations as the major elements. After considering factors such as initial costs, maintenance, and crash analysis the Virginia study concluded that two foot minimum width paved shoulders would be economically justified in that state for all new four-lane highways and on two-lane roads that exceed certain traffic volume thresholds.

A 1979 Minnesota Department of Transportation report (*7*) states that bituminous shoulders prove more economical than granular shoulders for new construction and overlays of two-lane roads, and with minimum design widths of four feet, a crash reduction of up to 15 percent can be realized.

In 1986 Wisconsin undertook a study (*8*) on providing paved shoulders on low-volume highways. This investigation relied on initial costs, maintenance expenditures, and crash experiences to develop extensive benefit/cost computations. In addition, judgment and experience of field personnel as well as public opinion were considered in drawing conclusions. Wisconsin's analysis resulted in recommendations to furnish three-foot-wide paved shoulders on any state trunk highway with traffic volumes in excess of 1,000 vpd.

The South Dakota Department of Transportation completed a study in 1997 (*9*) to evaluate shoulder surfacing with new construction in that state. The study, which was conducted by a consultant, included extensive reviews of shoulder conditions and performance and analyzed comparative maintenance costs for several shoulder materials. This research presented several interesting conclusions and recommendations and found that gravel shoulders exhibit lower life cycle costs. However the investigation did not include an in-depth consideration of safety benefits. Also most of the gravel shoulder segments analyzed were adjacent to mainline pavements with widths extended from 12 to 42 inches. One of the study recommendations was to extend pavement widths by two feet when using gravel shoulders. Therefore, many of the benefits of partially paved shoulders would be achieved through wider mainline pavement.

A 1998 study in Israel (*10*) found benefits in providing paved shoulders on high-volume two-lane rural roads. A significant reduction in crashes, up to 70 percent, and increased capacity resulting from use of paved shoulders by slow moving vehicles were observed. This study also developed criteria to aid in decisions of when to provide paved shoulders on two-lane roads.

Effects of Variable Shoulder Width, Paved and Unpaved

Several studies have been completed in recent years to analyze the potential safety and operational benefits associated with shoulder width.

In 1975 the Minnesota Department of Transportation, using 1973 data, found a decrease in crash rates with a variety of highway factors and features, including shoulder width and surface type (*11*).

A 1979 California study (*12*) conducted before-and-after analysis of shoulder widening improvements and found significant resultant accident (crash) rate reductions for all traffic volumes. Study projects included shoulder widening of varying widths on two-lane rural roads, with and without passing lanes.

A 1980 Transportation Research Board (TRB) review of existing studies (*13*) found wider shoulders lead to safer conditions in general and shoulder stabilization effective in reducing crash rates on two-lane roads. Shoulder widening was concluded to be cost effective in high crash rate locations for shoulders with an existing width of four feet or less. However, this may not be true for low-volume roads. The cost benefits for shoulder paving were not established with this review.

Michigan conducted a study of urban roads in 1981 (*14*) and did not find a significant reduction in crash frequency associated with increased shoulder widths. Certain crash types such as head-on, overturn, and even overall rates did not seem to be affected by shoulder width. This study did not consider shoulder type.

In 1981 the SAFE Association (*15*) found in a California review that that shoulder widening can be cost effective on higher volume high crash rate locations on two-lane rural roads. This study also found paving of shoulders to be beneficial in reducing crashes.

Several studies have been conducted in Texas to examine the potential benefits of paved shoulders. In 1981 a Texas research report (*16*) reviewed accident (crash) rates on three types of rural highway: two-lane with and without paved shoulders and four-lane undivided without paved shoulders. Traffic volumes ranging from 1,000 to 7,000 vpd were considered. This study concluded that full-width paved shoulders are effective in reducing crash rates, particularly for certain crash types such as run-off-road. The report further stated that paved shoulders may also reduce intersections related crashes on these road types. A 1982 study in Texas (*17*) found that the addition of full-width paved shoulders can be effective in reducing total crashes on rural two-lane roads. This conclusion was supported in 1989 (*18*) when another Texas review considered crash rates, edge maintenance, shoulder surface maintenance, and travel time in determining benefits of wider paved shoulders. This study concluded that 6 to 10 foot wide paved shoulders are cost beneficial for rural two-lane roads with volumes greater than 1,500 vpd.

Several studies of this and related topics have been conducted in Australia. In 1983 (*19*) it was concluded that sealed (paved) shoulders do provide safety and operational benefits over granular shoulders, but the effects of varying widths were unclear.

In 1987 a North Carolina report (*20*) provided a synthesis of prior research from several states on various factors relating safety to certain highway features such as lane width and shoulder width and type on rural two-lane roads. Four studies in particular were cited in concluding that these factors do indeed have a significant impact on safety, again with certain crash types such as run-off-road and opposite-direction crashes. Higher crash rates were found on roads with unstabilized shoulders (crushed stone, gravel, and turf) than on those with stabilized (paved) shoulders. This study produced a table of data for predicting anticipated crash reductions for various rural roadway improvements such as lane widening, shoulder widening, and shoulder paving.

A study published by the Federal Highway Administration in 1992 (*21*) found that shoulder widening can have significant benefits in reducing certain crash types such as run-off-road, head-on, and sideswipe crashes. These desirable impacts are increased by an additional 3–6 percent when the shoulders are also paved. This study, when considering only two-lane rural roads, also documented the safety improvements achieved from lane widening, but paving of shoulders in conjunction with these improvements always resulted in additional crash rate reductions.

The *Transportation Research Record* in 1995 reported a North Carolina study (*22*) that summarized various relationships between crash experience and roadway elements including lane, bridge, and shoulder width, shoulder type, and roadside features. One of the findings of this study was that shoulder widening may reduce related crashes by up to 49 percent with the addition of eight-foot paved shoulders.

Benefits of Rumble Strips with Paved Shoulders

While the effectiveness of paved shoulders in reducing crashes on certain roads has been documented, the additional installation of rumble strips or other form of audible warning for errant vehicles has been somewhat controversial. Several studies have been conducted to review the effects of rumble strips.

The *Transportation Research Record* reported in 1981 (*23*) that rumble strips did prove beneficial in reducing run-off-road crashes and also in extending the service life of shoulders.

In 1996 the Colorado Department of Transportation (*24*) found good benefits from the use of chip seals and well as conventional rumble strips in providing audible and visual warning to vehicles leaving the driving lanes.

A review by the *Transportation Research Record* in 1999 (*25*) found that continuous rumble strips on rural freeway shoulders reduced single-vehicle run-off-road crashes by over 21 percent with insignificant adverse effects.

Other Benefits of Paved Shoulders

Documentation of the value of paved shoulders to bicycle travel and overall transportation safety can also be found in the Institute of Transportation Engineers (ITE) *Traffic Safety Tool Box* (*26*), which notes that four to six foot minimum width paved shoulders are very important for safe bicycle use, especially on rural roads with speeds in excess of 35 mph. These features can reduce wrong-way bicycle travel, a leading crash cause, but also reduce motorist crashes and have a 10-year payback from reduced maintenance.

A bicycle system plan completed by the Maricopa County (Arizona) Transportation Department in 1999 (*27*) concluded that paved shoulders/bicycle lanes in urban areas can add four to six percent to the cost of initial construction, but benefits from reduced crashes and expected shift in travel from motor vehicles to bicycles could result in a benefit cost ratio of 3.75.

Table 1. Literature Summary

Ref	Considerations									Results				
	Roadway Characteristics							Other		Crash Rate/ Crash Reduction	Capacity/ Travel Time	Reduced Maint./ Cost	Cost Effect-ive	Conclusions
	Road Type	No. Lanes	Lane Width	ADT	Shoulder Type	Shoulder Width	Rumble Strips	Const. Costs	Crash Type					
2	Rural	2	—	> 2,000–3,000	Paved	3–4 ft	—	Yes	—	Yes	—	—	Yes	Found that lower crash rates were associated with paved shoulders. Paved shoulders 3–4 ft on rural two-lane roads with ADT > 2,000–3,000 are cost effective.
3	Rural	2	—	—	Paved	24–28 inches	—	Yes	Yes	Yes	—	—	—	Concluded that shoulders 24–28 inches wide reduce fatality crash rates on rural two-lane roads.
4	—	—	—	—	Paved vs. granular	—	—	—	Yes	Yes	—	—	—	Found 3–4 times lower crash rates on roads with paved shoulders.
10	Rural	2	—	High volume	Paved	—	—	—	—	Yes	Yes	—	—	Paved shoulders reduce crashes 70 percent and increase capacity.
12	Rural	2	—	All	—	Yes	—	—	—	Yes	—	—	—	Found that shoulder widening reduces crash rates for all traffic volumes.
13	—	2	—	Yes	Yes	Yes	—	—	—	Yes	—	—	Yes	Wider shoulders lead to safer conditions. Widening shoulders is cost effective in high crash locations
14	Urban	—	—	—	—	Yes	—	—	Yes	Yes	—	—	—	Did not find a significant reduction in crashes associated with increased shoulder widths.
15	Rural	2	—	High volume	Paved	Yes	—	—	—	Yes	—	—	Yes	Shoulder widening can be cost effective on higher volume roads with high crash rates on two-lane rural roads. Paving shoulders can reduce crashes
16	Rural	2 or 4	—	1,000–7,000	Paved vs. unpaved	—	—	—	Yes	Yes	—	—	—	Full-width paved shoulders reduce crash rates, particularly for run-off-road crashes. Paved shoulders may reduce intersection related accidents.
17	Rural	2	—	—	Paved	Yes	—	—	—	Yes	—	—	—	Addition of full-width paved shoulders can reduce crashes on rural two-lane roads.
18	Rural	2	—	1,500	Paved	6–10 ft	—	—	—	Yes	Yes	Yes	Yes	6–10 ft paved shoulders are cost beneficial for rural two-lane roads with volumes greater than 1,500 vpd.
19	—	—	—	—	Paved vs. granular	Yes	—	—	—	Yes	—	—	—	Paved shoulders are safer than unpaved shoulders, but effects of width are not clear.
20	Rural	2	Yes	—	Yes	Yes	—	—	Yes	Yes	—	—	—	Higher crash rates are found on roads with unstabilized shoulders compared to stabilized shoulders.
21	Rural	—	—	—	—	—	—	—	Yes	Yes	—	—	—	Significant crash reductions found for various roadway improvements, including paved shoulders.
23	—	—	—	—	—	—	Yes	—	Yes	Yes	—	Yes	—	Rumble strips are beneficial in reducing run-off-road crashes and extend the service life of shoulders.

Ref	Considerations									Results				
	Roadway Characteristics							Other		Crash Rate/ Crash Reduction	Capacity/ Travel Time	Reduced Maint./ Cost	Cost Effect-ive	Conclusions
	Road Type	No. Lanes	Lane Width	ADT	Shoulder Type	Shoulder Width	Rumble Strips	Const Costs	Crash Type					
24	—	—	—	—	—	—	Yes	—	—	—	—	—	—	Found benefits in providing audible warning to vehicles leaving the driving lanes.
26	Rural w/ speed > 35 mph	—	—	—	Paved	4 to 6 ft	—	—	Yes	Yes	—	Yes	Yes	Paved shoulders can reduce wrong way bicycle travel, a leading crash cause but also reduce motorist crashes and have a 10-year payback from reduced maintenance.
27	Urban	—	—	—	Paved	—	—	—	—	—	—	—	Yes	Paved shoulders could result in a benefit cost ratio of 3.75.
28*	Rural	—	—	Low volume	Paved vs. granular	—	—	—	—	Yes	—	—	—	Paved shoulders are safer than unpaved shoulders on rural roads and have lower crash rates even with low traffic volumes.
29*	—	2 and 4	—	Yes	Paved	2 ft (min)	—	Yes	—	—	—	Yes	Yes	2 ft minimum wide shoulders are economically justified on all new two- and four-lane roads that exceed a certain volume.
30*	—	2	—	—	Paved vs. unpaved	4 ft (min)	—	Yes	—	Yes	—	—	Yes	Bituminous shoulders are more economical than granular shoulders for new construction and overlays of two-lane roads. A 4 ft minimum design width can reduce crashes up to 15 percent.
31*	—	—	—	Low volume	Paved	Yes	—	Yes	—	—	—	Yes	Yes	3-ft-wide paved shoulders should be applied to any state highway with volume over 1,000 vpd.
32*	—	—	Yes	—	Yes	—	—	—	—	—	—	Yes	Yes	Recommended to extend pavement widths two feet past mainline. Found lower life cycle costs for gravel shoulders.
33*	—	—	—	—	Yes	Yes	—	—	—	Yes	—	—	—	Found reduction in crash rates with variety of shoulder widths and surface types.
34*	Rural	2	Yes	—	Yes	Yes	—	—	Yes	Yes	—	—	—	Shoulder widening can reduce certain crash types. Lane widening and shoulder paving can also have benefits.
35*	Rural freeway	—	—	—	—	—	Yes	—	Yes	Yes	—	—	—	Continuous rumble strips on rural freeways reduce single vehicle run-off-road crashes by over 21 percent.

*Note: These references are provided in the table for comparison but are not further discussed in the report. In addition, other references were reviewed, but not included in this listing. Please see Reference page for complete reference information.

SHOULDER DESIGN PRACTICES IN IOWA AND NEIGHBORING STATES

A survey conducted as part of other research (*6*) revealed the use of paved shoulders to be quite extensive across the country. Survey responses indicated the following:

- Paved shoulders are specified for certain roads by 32 of 35 responding states, with most or all shoulders paved by 15 of those respondents.
- 14 states use minimum threshold criteria to warrant paving shoulders.
- Minimum paving width of 2 feet or greater is used by 21 of 35 responding states.

As part of a data gathering effort for the present research, design staff in all states adjacent to Iowa were contacted to obtain current practices and criteria for including paved shoulders with new construction and 3R rehabilitation improvements. Following a description and table (Table 2) of Iowa's design practices, a summary and table of each neighboring state's design practices and criteria for providing paved shoulders adjacent to primary highways are given.

Iowa

On four-lane freeways and expressways, the inside travel lane is designed 12 feet wide and the outside lane is 14 feet. (Actual lane width is 12 feet. Painted edge line is offset 2 feet from the edge of the paved lane.) Median shoulders are 6 feet wide and outside shoulders are specified as 8 feet (actual shoulder width is 10 feet due to extra 2 feet of lane pavement width outside the painted edge line). All interstate shoulders are paved. Expressway shoulders are granular unless design year ADT exceeds 10,000, then paved shoulders will be considered. Rural two-lane roadways on the National Highway System (NHS) have lane widths designed at 14 feet, but the painted edge line is offset from centerline to provide 12-foot-wide travel lanes. Shoulders on NHS routes are thus 2 feet paved and 8 feet granular, but on non-NHS routes shoulders are designed as 10 feet granular that can be reduced to 6 to 8 feet if design year ADT is less than 3,000. Iowa's 3R standards do not include adding paved shoulders to existing routes.

Where portland cement concrete pavements are built, rumble strips are provided in the 2 feet outside of the painted edge line on all classes of roadways. Where full-width paved shoulders are constructed, rumble strips are provided regardless of pavement type.

Table 2. Iowa Shoulder Design Practices

Roadway Type or ADT	Shoulder Width	Shoulder Type	Comments
Interstates and non-interstate applications w/ ADT > 10,000	Outside shoulder: 10 ft Inside shoulder: 6 ft	Paved	Rumble strips are included w/ full-width paved shoulders.
Other four-lane divided freeways and expressways	Outside shoulder: 8 ft Inside shoulder: 6 ft	Paved and granular	14-ft-wide outside lane results in 2-ft paved shoulder.
NHS Highways	10 ft	2 ft paved and 8 ft granular	14-ft lanes are paint striped at 12-ft, resulting in 2-ft paved shoulders.
Rural two-lane highways for non-NHS routes	8–10 ft	Granular	6–8 ft width for ADTs less than 2,000.

Illinois

With new and reconstructed freeways, Illinois uses 10 to 12 foot wide paved shoulders depending on projected number of trucks. Rural expressways are designed with 10-foot-wide paved right shoulders and 6-foot-wide left shoulders, of which 4 feet are paved. Urban expressways have 10-foot-wide paved shoulders on both sides. Four-lane strategic arterials feature 10-foot-wide paved right shoulders and 6 to 8 foot wide left shoulders, of which 4 feet are paved, considering number of projected trucks. Minor four-lane arterials are similar except right shoulders are a minimum of 10 feet wide, of which 8 feet is paved. Rural two-lane principal arterials have 10-foot-wide paved shoulders but minor arterials and collectors have 8 to 10 foot wide shoulders, of which 4 feet are paved. Design criteria in Illinois for 3R improvements allow 3-foot-wide paved shoulders on roads with ADT exceeding 3,000 and 1–2 foot wide paved shoulders on roads with ADT ranging from less than 1,000 to 3,000. All 3R improvements also provide an aggregate fillet with paved shoulders.

Rumble strips are provided on interstates and freeways. Primary highways have rumble strips at high accident locations, particularly those involving run-off-road crashes. Other locations are considered for this treatment on a case-by-case basis, but use of rumble strips where bicycle traffic exists is avoided unless crash history warrants.

Illinois information was provided by Roger Driskell, P.E., engineer of policy and procedures, Illinois Department of Transportation, Springfield, Illinois. See Table 3 for summary.

Table 3. Illinois Shoulder Design Practices

Roadway Type or ADT	**Shoulder Width**	**Shoulder Type**	**Comments**
Freeway	10–12 ft both sides	Paved	Depends on number of trucks.
Rural expressways	Right shoulder: 10 ft Left shoulder: 6 ft	Paved and unpaved	4 ft of shoulders are paved.
Urban expressways	10 ft both sides	Paved	
Four-lane strategic arterials	Right shoulder: 10 ft Left shoulder: 6–8 ft	Paved and unpaved	4 ft of shoulders are paved, depending on truck traffic
Minor four-lane arterials	Right shoulder: 10 ft min. Left shoulder: 6–8 ft	Paved and unpaved	8 ft of shoulders are paved.
Rural two-lane principal arterials	10 ft both sides	Paved	
Minor arterials and collectors	8–10 ft both sides	Paved	4 ft of shoulders are paved.
ADT > 3,000	3 ft. minimum	Paved	3R Criteria
ADT < 1,000–3,000	1–2 ft. minimum	Paved	3R Criteria

Minnesota

For all multi-lane roads, Minnesota specifies 6 to 10 foot wide paved right shoulders for urban arterials and collectors. Left shoulders in urban areas are 4 to 10 feet wide and paved, depending on the number of lanes. Multi-lane roads in rural areas have 11.5 foot usable width right shoulders, of which 10 feet is paved. Left side shoulders in rural areas have 5.5 to 11.5 feet of usable width, of which 4 to 10 feet is paved. For two-lane and multi-lane undivided roads, Minnesota uses 9.5 to 11.5 foot usable width shoulders, of which 8 to 10 feet are paved for all rural arterials with traffic volumes exceeding 3,000 vpd. All other rural roads have 4 to 8 foot wide surfaced shoulders with a minimum of 1.5 feet paved. Urban two-lane and undivided roads feature 6 to 10 foot wide paved shoulders, depending on design speed and parking allowances. Minnesota also recommends a minimum paved shoulder width of 4 feet if bicycle usage is anticipated.

Current Minnesota guidelines specify rumble strips on all rural highways, two-lane and multi-lane, with speed limits over 50 mph and shoulder widths 6 feet or greater. In addition, rumble strips are also installed in the left shoulder of multi-lane roads. Several designs of rumble strips are employed, depending on type of roadway. Rumble strips are not recommended where bicycle traffic exists and shoulder widths are 4 feet or less, unless a high run-off-road crash rate is noted.

Minnesota information was provided by Amr Jabr, P.E., design standards engineer, Minnesota Department of Transportation, Minneapolis, Minnesota. See Table 4 for summary.

Table 4. Minnesota Shoulder Design Practices

Roadway Type or ADT	Shoulder Width	Shoulder Type	Comments
Multi-lane urban arterial	Right shoulder: 6–10 ft Left shoulder: 4–10 ft	Paved	Shoulder width depends on number of lanes.
Multi-lane rural roads	Right shoulder: 11.5 ft Left shoulder: 5.5–11.5 ft	Paved and unpaved	10 ft is paved on right shoulder, while 4–10 ft is paved on left shoulder.
Two-lane and multi-lane undivided roads	9.5–11.5 ft	Paved and unpaved	8–10 ft is paved for all rural arterials with traffic volumes > 3,000 vpd.
Other rural roads	4–8 ft	Paved and unpaved	Minimum of 1.5 ft paved.
Urban two-lane and undivided roads	6–10 ft	Paved	Width depends on design speed and parking allowances.

Missouri

Missouri uses a three-tiered classification system for pavements based on predicted equivalent single axle loadings (ESALs). Light duty rural pavements include paved shoulders of variable width for all roads with traffic volumes exceeding 3,500 ADT. Medium- and heavy-duty rural pavements feature paved shoulders for all ADTs. Divided roadways have 4 foot inside and 10 foot outside shoulders, but six-lane divided use 10-foot shoulders left and right. With all pavement classifications, a 2-foot section of widened pavement adds to the paved shoulder width except for the inside shoulder of divided sections. Paved shoulders are specified in all locations where expansion is considered eminent. In urban areas, all roads with traffic volumes exceeding 20,000 ADT have 10–12 feet wide paved shoulders. Missouri specifies a minimum 4-foot-wide paved bicycle path adjacent to roadways where warranted. All 3R improvements on roads with traffic volumes over 3,500 ADT include paved shoulders with the design.

Rumble strips are also provided on paved shoulders in Missouri and located to facilitate bicycle traffic where needed.

Missouri information was provided by Sam Masters, P.E., assistant state design engineer, Missouri Department of Transportation, Jefferson City, Missouri. See Table 5 for summary.

Table 5. Missouri Shoulder Design Practices

Roadway Type or ADT	**Shoulder Width**	**Shoulder Type**	**Comments**
Light-duty rural pavements w/ > 3,500 ADT	Variable	Paved	New
Medium- and heavy-duty rural pavements w/ all ADTs	Variable	Paved	New
Urban roads w/ > 20,000 ADT	Variable	Paved	New
All roads > 3500 ADT	Variable	Paved	3R criteria

Nebraska

A priority commercial system of roads has been established in Nebraska consisting of approximately 30 percent of the state primary roads. Design standards for this system include 10-foot-wide shoulders, of which 8 feet are paved. In addition, any other route with a design year traffic of 3,000 ADT or greater will also have 8-foot-wide paved shoulders. Inside shoulder widths are 6 feet wide with 4 feet paved for rural interstates and 5 feet wide with 3 feet paved for four-lane divided expressways. Interstates with six lanes have 12-foot-wide inside shoulders with 10 feet paved; if a median barrier exists, paved inside shoulder widths increase to 12 feet for interstates and 10 feet for expressways. To address extensive erosion in the Sandhills area, Nebraska designs roads with paved widths of 28 feet and painted with a 24-foot driving width, resulting in effective 2-foot-wide paved shoulders. This practice has now been extended to other roads with traffic volumes as low as 850 ADT.

Nebraska mills rumble strips in both inside and outside shoulders of divided interstates and expressways, with strips placed 6 inches from the pavement edge. Consideration is being given to placing rumble strips on two-lane roads with minimum of 8-foot-wide paved shoulders.

Nebraska information was provided by Eldon Poppe, P.E., roadway design engineer, and Phil TenHulzen, P.E., design standards engineer, Nebraska Department of Roads, Lincoln, Nebraska. See Table 6 for summary.

Table 6. Nebraska Shoulder Design Practices

Roadway Type or ADT	Shoulder Width	Shoulder Type	Comments
Priority commercial system road	10 ft	Paved and unpaved	8 ft are paved.
Any road w/ ADT > 3,000 vpd	8 ft	Paved	
Four-lane divided freeways and expressways	Inside: 5 ft	Paved and unpaved	3 ft are paved.
ADT > 850 vpd	—	Paved and unpaved	2-ft-wide paved shoulders result from total paved width of 28 ft.

South Dakota

South Dakota includes paved shoulders of varying widths for most new construction and reconstruction projects. For roads with traffic volumes less than 550 vpd, 2 to 4 foot wide shoulders of the same material as the mainline pavement are used. Higher volume (550–2,500 vpd) two-lane rural and urban roads have a mainline pavement width of 28 feet, which effectively provides 2-foot-wide paved shoulders. The remaining shoulders for these roads are granular. For two-lane roads with traffic exceeding 2,500 vpd, 8-foot-wide paved shoulders are provided. Divided four-lane arterials in South Dakota feature 8-foot-wide outside and 4-foot-wide inside paved shoulders.

All paved shoulders and widened pavements in South Dakota have rumble strips installed.

South Dakota information was provided by Bernie Clocksin, P.E., lead project engineer, South Dakota Department of Transportation, Pierre, South Dakota. See Table 7 for summary.

Table 7. South Dakota Shoulder Design Practices

Roadway Type or ADT	Shoulder Width	Shoulder Type	Comments
ADT < 550	2–4 ft	Same material as mainline pavement	
Two-lane rural and urban roads w/ ADT 550–2,500	2 ft minimum	Paved and unpaved	2-ft-wide paved shoulders result from total paved width of 28 ft, remaining shoulder is granular.
Two-lane roads w/ ADT > 2,500	8 ft	Paved	
Divided four-lane arterial	Right shoulder: 8 ft Left shoulder: 4 ft	Paved	

Wisconsin

Design criteria in Wisconsin recommend shoulder widths of 6 to 10 feet, with a minimum of 3 feet paved for two-lane rural state trunk highways classified as arterials and for all others with ADTs over 1,250. Furthermore, any state road with motorized vehicles in excess of 1,000 per day and bicycle traffic exceeding 25 per day during the normal season shall have paved shoulders. Paved shoulders for bicycle use are a minimum of 5 feet wide. Multi-lane expressways and freeways in Wisconsin feature right shoulders of 10-foot width, 8 to 10 feet paved, and left shoulders of 6 to 10 feet, with 3 to 10 feet paved.

Paved shoulders include rumble strips in most locations in Wisconsin.

Wisconsin information was provided by John Haverberg, P.E., state design engineer, Wisconsin Department of Transportation, Madison, Wisconsin. See Table 8 for summary.

Table 8. Wisconsin Shoulder Design Practices

Roadway Type or ADT	**Shoulder Width**	**Shoulder Type**	**Comments**
Rural state truck highways classified as arterials or ADT > 1,250	6–10 ft	Paved and unpaved	Minimum of 3 ft paved
State road w/ ADT > 1,000 and bicycle traffic > 25 bicycles per day (bpd)	5 ft minimum	Paved	
Multi-lane expressways and freeways	Right shoulder: total 8-10 ft Left shoulder: total 6–10 ft	Paved and unpaved	The right shoulders are 8–10 ft paved, and the left shoulders are 3–10 ft paved. Most paved shoulders include rumble strips.

COST ESTIMATIONS

A major consideration for inclusion of paved shoulders in standard design criteria is increased cost as compared to granular surfaced shoulders. It is accepted that paved shoulders offer numerous benefits in terms of safety, reduced maintenance, driver comfort, and operational improvements, but these advantages must be weighed in terms of additional impacts to the annual highway improvement program.

The practice of many states, as supported by numerous research studies, is to provide minimum 3-foot-wide paved shoulders adjacent to roads carrying specified minimum traffic volumes. For roads that also serve significant bicycle travel, some states specify minimum 4-foot-wide paved shoulders. In recognition of these commonly accepted minimums, the following estimate of costs for construction of paved shoulders in Iowa is presented.

Initial Costs

Paved Shoulder versus Granular Shoulder

Using data from the Iowa DOT average contract bid prices for calendar year 2000, the following initial costs were determined. Note that these estimates are only for the width shown. It is assumed that the remaining shoulder in all examples would consist of granular material. Added costs of excavation, subbase, traffic control, and mobilization are not included. (See Appendix A for additional comparative improvement costs.)

- Asphalt cement concrete (ACC) Type B paved shoulder, eight-inch thick: $15.19/s.y.
- Granular shoulder, eight-inch thick: $11.52/ton or $3.80/s.y.

For a design width of 3 feet, cost per mile for a two-lane roadway is estimated as follows:

- Paved shoulders: $53,469/mile of roadway
- Granular shoulders: $13,376/mile of roadway

A minimum design width to accommodate bicycle traffic (4 feet) is estimated as follows:

- Paved shoulders: $71,286/mile of roadway
- Granular shoulders: $17,833/mile of roadway

A desirable design width for bicycles (6 feet) is estimated as follows:

- Paved shoulders: $106,938/mile of roadway
- Granular shoulders: $26,752/mile of roadway

In addition to initial investment, increased restoration costs would also be incurred at the end of effective service life. Again using Iowa DOT average contract bid prices, these extra costs would average approximately $4/s.y., or about $14,000/mile for 3-foot shoulders on a two-lane road.

Initial Construction of Wider Pavement

For initial construction, a viable option is wider pavement, with extra width dedicated to paved shoulders. For example, current design standards for four-lane and many two-lane improvements in Iowa specify 14-foot-wide traffic lanes with the outside 2 feet considered part of the shoulder. By widening the initial paving dimension, a desired paved shoulder surface width can be obtained at the following estimated costs:

- Four-lane freeway and expressway, 27-foot width to present 3-foot-wide paved shoulders on outside only: $15,262/mile for additional foot beyond current standards
- Two-lane Super 2 and NHS highways, 30-foot width to present 3-foot-wide paved shoulders on both sides: $30,524/mile for additional foot on each side
- Other two-lane designs, 30-foot width for 3-foot-wide paved shoulders on both sides: $91,572 for 6 feet additional total width

Where a minimum 4-foot paved shoulder width to accommodate bicycle travel is desired, an additional $15,262/mile per foot of widening should be added to these estimates.

These estimates use the Iowa DOT year 2000 average contract bid price of approximately $26/s.y. for 10-inch portland cement concrete (PCC) Class C pavement, and do not include mobilization, traffic control, subbase, etc. Also cost of reduced quantity of replaced granular shoulder material is not included.

For the first two categories, increasing initial paving width to provide resultant 3–4 foot paved shoulders may be a more efficient and cost effective option to a separate construction phase for this shoulder work.

Alternatives

In addition to the options presented above, several alternatives can be considered for providing paved shoulders of various widths and road classifications. The following options are presented to compare costs of investment strategies for providing paved shoulders of minimum- through full-width for four-lane and two-lane roads.

The computations for these alternatives do not include mobilization, traffic control, or subbase costs.

<u>Alternative 1—Four-Lane Expressways: Full-Width Paved Shoulders, 10-foot Right Side and 6-foot Left Side</u>

Many other states specify full-width paved shoulders for high-volume and classification roadways. Total added paved shoulder width is 14 feet or 16,427 s.y./mile of four-lane roadway. Using an average paved shoulder cost of $15.19/s.y. and granular shoulder cost of $3.80/s.y. for material replaced, **the net cost for Alternative 1 is estimated at $187,103/mile of four-lane roadway.**

Alternative 1—Super 2 Highways: Full-Width Paved Shoulders, 10-foot Both Sides

Total added paved shoulder width is 16 feet or 9,387 s.y./mile of roadway. Using an average paved shoulder cost of $15.19/s.y. and granular shoulder cost of $3.80/s.y. for material replaced, **the net cost for Alternative 1 is estimated at $106,918/mile of Super 2 roadway.**

Alternative 2—Four-Lane Expressways: Minimum 6-foot-wide Paved Shoulders, Left and Right Sides

Since current Iowa design standards provide a 26-foot-wide pavement (14 foot outside and 12 foot inside lanes), this alternative would require 4 additional feet of paved shoulder on the right side and 6 feet on the left, or inside, shoulder. Total added paved shoulder width is 10 feet or 11,733 s.y./mile; at $15.19/s.y. the cost per mile of roadway would be $178,224. The cost should be reduced by the cost of granular shoulders replaced, 11,733 s.y. at $3.80/s.y. = $44,585/mile. Thus, **the net cost for Alternative 2 is estimated at $133,639/mile of four-lane roadway.**

Alternative 2—Super 2 Highways: Minimum 6-foot-wide Paved Shoulders, Both Sides

Considering current Iowa design standards of 28 feet pavement width, this option would require an addition of 4 feet to each side. Total added paved shoulder width is 8 feet or 4,693 s.y./mile; at 15.19/s.y. the cost per mile of roadway would be $71,287/mile. This cost should be reduced by the cost of granular shoulders replaced, 4,693 s.y. at $3.80/s.y. = $17,833/mile. Thus, **the net cost for Alternative 2 is estimated at $53,454/mile of Super 2 roadway.**

Alternative 3—Four-Lane Expressways: Minimum 4-foot-wide Paved Shoulder Right Side and 2 foot-wide Paved Shoulder Left Side

This option would add a total of 4 feet of paved shoulder to each roadway (2 feet on each side). Total added shoulder width is 4 feet or 4,693 s.y./mile; at $15.19/s.y. the cost per mile of roadway would be $71,287/mile. The cost should be reduced by the cost of granular shoulders replaced, 4,693 s.y. at $3.80/s.y. = $17,833/mile. Thus, **the net cost of Alternative 3 is estimated at $53,454/mile of four-lane roadway.**

Note that extending the initial pavement width to 30 feet would also provide paved shoulders of these dimensions, but the extra cost is estimated at $104,185/mile of four-lane roadway using the contract price of $26/s.y. for 10-inch PCC pavement.

Alternative 3—Super 2 Highways: Minimum 4-foot-wide Paved Shoulders, Both Sides

This option would add 2 feet of paved shoulder to each side. Total added shoulder width is 4 feet or 2,347 s.y./mile; at $15.19/s.y. the cost per mile of roadway would be $35,651/mile. The cost should be reduced by the cost of granular shoulders replaced, 2,347 s.y. at $3.80/s.y. = $8,919/mile. Thus, **the net cost for Alternative 3 is estimated at $26,732/mile of Super 2 roadway.**

Note that placing wider pavement initially (32 feet) to achieve the same total paved surface width is estimated to cost approximately $52,100/mile.

A summary of cost estimates is included in Table 9. The comparative standards, costs, and impacts of the paved shoulder alternatives are tabulated in Appendix B.

Table 9. Summary of Cost Estimates

Roadway Type	Pavement Width	Const. Type	Shoulder Type	Shoulder Width*	Cost, paved only unless noted
Two-lane rural	—	Retrofit	Paved	3 ft	$53,469/mile
Two-lane rural	—	Retrofit	Granular	3 ft	$13,376/mile
Two-lane rural	—	Retrofit	Paved	4 ft	$71,286/mile
Two-lane rural	—	Retrofit	Granular	4 ft	$17,833/mile
Four-lane freeway/expressway	27 ft (widened pavement)	Initial	Paved	Provide 3 ft outside only paved	$15,262/mile for additional foot on outside only
Four-lane freeway/expressway	30 ft (widened pavement)	Initial	Paved	4 ft on right side, 2 ft on left side	$104,185/mile of four-lane roadway
Four-lane freeway/expressway Alternative 1 (10-foot right, 6-foot left paved shoulders)	26 ft	Retrofit/initial	Paved full-width	Additional 8 ft on right side, additional 6 ft on left side	$187,103/mile of four-lane roadway
Four-lane freeway/expressway Alternative 2 (6-foot paved shoulders)	26 ft	Retrofit/initial	Paved	Additional 4 ft on right side and additional 6 ft on left side	Net cost of $133,639/mile of four-lane roadway
Four-lane freeway/expressway Alternative 3 (4-foot right, 2-foot left paved shoulders)	26 ft	Retrofit/initial	Paved	Additional 2 ft on both sides	Net cost of $53,454/mile of four-lane roadway
Two-lane Super 2 and NHS highways	30 ft (widened pavement)	Initial	Paved	Provide 3 ft on both sides paved	$30,524/mile for additional foot on each side
Super 2 highways	32 ft (widened pavement)	Initial	Paved	4 ft on both sides	$52,100/mile
Super 2 highways Alternative 1 (10-foot paved shoulders)	28 ft	Initial	Paved full-width	Additional 8 ft on both sides	$106,918/mile of roadway
Super 2 highways Alternative 2 (6-foot paved shoulders)	28 ft	Initial	Paved	Additional 4 ft on both sides	Net cost of $53,454/mile
Super 2 highways Alternative 3 (4-foot paved shoulders)	28 ft	Initial	Paved	Additional 2 ft on both sides	Net cost of $26,732/mile
Other two-lane designs	30 ft (widened pavement)	Initial	Paved	Provide 3 ft on both sides	$91,572/mile for 6 feet additional total width

*Paved width only; remaining shoulder is granular.

Maintenance Costs

Higher initial costs will be at least partially offset by reduced annual maintenance expenditures. For granular shoulders, common maintenance efforts include repair with aggregate and blading. Average Iowa DOT expenditures for these activities for the fiscal years 1996–2000 totaled $4,794,000/year or about $259/lane-mile. Standard maintenance for paved shoulders includes repair with bituminous material, sealing edge ruts, filling shoulder joints, and other paved shoulder repairs. Over those same five years, Iowa DOT statewide maintenance costs for paved shoulders averaged $329,000/year or about $76/lane-mile. The cost savings for paved vs. granular shoulders total approximately $366/mile/year for a two-lane road.

While reduced maintenance will not offset the higher initial cost of paved shoulders, even at a width of 3 feet, these savings must be taken into account in the consideration of this design improvement. Other benefits are discussed in another section of this report.

ANALYSIS OF CRASH HISTORY IN IOWA

To assess the effects paved shoulders may have in Iowa, an investigation of crash history was undertaken utilizing the Accident Location and Analysis System (ALAS) database that is maintained by the state. Records were reviewed for existing four-lane divided rural non-interstate freeways and expressways as well as selected two-lane rural roads. Various widths, shoulder surface types, years of record, and crash type were considered.

Except for the interstate system, Iowa has historically specified granular surfaced shoulders for most of the primary network of roads, four-lane and two-lane. This design criterion has been followed in recognition of acceptable economic service provided by granular shoulders augmented by Iowa's abundant sources of crushed limestone and dolomite in most locations. The major exception is found in the northwestern counties, where only some deposits of natural gravel are commercially available. Consequently, very few miles of rural roads with paved shoulders are available for comparative analysis. In addition, other design features for rural sections may not be comparable such as geometrics, access restrictions, age of roadway, shoulder width, and years of available crash data. For example, in reviewing records of four-lane expressways, only approximately 28 miles with paved shoulders could be identified for acceptable analysis compared to about 300 miles with granular surfacing. A similar observation was found for two-lane rural roads, where only some sections in northwest Iowa include paved shoulders, and this fact along with other aforementioned factors, presented a relatively small sample for comparative analysis.

However, analysis of crash history was undertaken for four-lane divided and selected two-lane rural roads in Iowa and data indicated some benefit that could possibly be attributable to paved shoulders; however, results were mixed. The small sample of paved shoulder sections available for study simply did not allow for drawing valid and defensible determinations.

It should be noted that the *Update Report on Speed Limits in Iowa* published by the Iowa Safety Management System (Iowa SMS) Task Force on Speed Limits (*36*) included an interesting result. That finding determined crash rates for the study period years of 1996–1999 were two to three times greater on fully access-controlled, non-interstate freeways than those exhibited on the interstate highway system in Iowa. Since all interstate highways in Iowa feature paved shoulders and most non-interstates do not and considering that many other key design features are similar, it could be concluded that, indeed paved shoulders may have a demonstrable benefit in reducing crash rates and even severity for this class of roadway.

COMPARATIVE ASSESSMENT USING CRASH DATA AND TRAFFIC VOLUME

Based on perceived benefits of paved shoulders, a comparative assessment of four-lane (non-interstate) roadways in Iowa was developed for potential shoulder improvements. This section outlines the procedures used to develop a comparative assessment focusing on corridor designation, overall traffic volume, commercial vehicles, and crash history.

Roadway Designation

Four-lane facilities located in rural areas, both incorporated and unincorporated, were identified from the Iowa DOT's Geographic Information and Management System (GIMS) database. Corridors were then defined based on state route numbers. When appropriate, locations currently with paved shoulders were included to preserve corridor continuity. Next, corridors were subdivided into shorter, variable-length segments representing potential improvement limits. Segments were defined using logical project termini, such as major intersections, cities, and/or changes in shoulder type (outside shoulder only), traffic volumes, or facility age.

Traffic Analysis

Average traffic and truck volumes for each corridor and corridor segment were calculated using the most recent (1999) average annual daily traffic (AADT) data from the GIMS "traffic" table. Since corridors and corridor segments were comprised of several variable-length GIMS sections, the following equations were used to calculate the corresponding weighted traffic volumes.

Weighted corridor AADT:

$$\sum \frac{GIMS.Length}{Corridor.Length}(GIMS.AADT) \tag{1}$$

Weighted corridor truck AADT:

$$\sum \frac{GIMS.Length}{Corridor.Length}(GIMS.SingleUnitTotal + Single \,\&\, MultipleTrailerTotal) \tag{2}$$

Weighted corridor segment AADT:

$$\sum \frac{GIMS.Length}{CorridorSegment.Length}(GIMS.AADT) \tag{3}$$

Weighted corridor segment truck AADT:

$$\sum \frac{GIMS.Length}{CorridorSegment.Length}(GIMS.SingleUnitTotal + Single \,\&\, MultipleTrailerTotal) \tag{4}$$

Crash Analysis

Crash data for a five-year analysis period (1995–1999) were obtained from the Iowa DOT's Geographic Information System–Accident Location and Analysis System (GIS-ALAS). Non-intersection crashes, designated in GIS-ALAS as occurring on a four-lane facility and spatially adjacent to the selected GIMS roadways, were extracted from this database. Intersection crashes were assumed non-shoulder-related and deleted from the data. In addition, a category of possible shoulder-related crashes was identified. These crashes were defined as those not occurring on the roadway or in the median. Median crashes were eliminated because only the outside shoulder type was considered in roadway designation. All crashes were then spatially assigned to the proximate GIMS sections.

Since several facilities were constructed or improved since 1995, a relative analysis period was defined for all GIMS sections. The relative analysis period was derived from the most recent year of a widening activity or original construction, in either direction of travel, as indicated in the GIMS "br_surface" table. A five-year analysis period was assumed if these activities occurred prior to 1995. If a major improvement activity occurred in 1995 or later, the analysis period was established beginning the following year. For example, if a four-lane roadway was constructed in 1996, the first full year of operation was assumed to begin in 1997, resulting in a crash analysis period of three-years, 1997–1999. These assumptions provide a reasonable estimate of facility age and eliminate the need to review site-specific plans, staging activities, and project completion dates. More rigorous site-specific analyses may be conducted as deemed appropriate when making final improvement selections.

Upon definition of relative analysis periods, total exposure (vehicle-miles of travel) was calculated for each GIMS section. Exposure is used in crash rate calculations to account for differences in traffic flow among analysis sites. Annual exposure along a section of roadway is the product of section length and total annual traffic. Given a multi-year analysis period, total exposure is determined by multiplying annual exposure and the length of the analysis period, in years.

Total exposure, vehicle-miles of travel:

$$(AADT)\left(\frac{365 days}{year}\right)(AnalysisPeriod, years)(SectionLength, mi) \qquad (5)$$

Exposure values for corridor sections were calculated using the most recent traffic data (1999), which were assumed to yield a reasonable estimate of exposure for the entire analysis period. Total exposure for corridor segments was calculated by summing exposures along individual GIMS sections within corridor segments (or partial segments). If traffic volumes have increased dramatically during the analysis period, the computed exposure value will be higher, perhaps resulting in an inaccurate lower crash rate. If this is a concern for a particular roadway segment, it is recommended that site-specific year-by-year analyses be conducted as part of improvement selection process. Total exposure was calculated by summing exposures along individual GIMS sections within corridor segments (or partial segments).

Comparative Assessments

The total number of crashes, total possible shoulder-related crashes, weighted traffic volumes, and total length were summarized for each analysis period and shoulder type within each corridor segment (see Figure 1 for corridors analyzed). Both total and non-median non-roadway crash rates, crashes per million vehicle-miles of travel (MVM), were calculated for each corridor segment (or partial segment) using the following equations.

Crash rate:

$$\frac{TotalNumberofCrashes\left(10^{6}\right)}{TotalExposure} \quad (6)$$

Possible shoulder-related crash rate:

$$\frac{TotalNumberofNonMedian, NonRoadwayCrashes\left(10^{6}\right)}{TotalExposure} \quad (7)$$

Individual full corridors were ranked in comparison to other selected four-lane corridors statewide, comparing weighted total traffic and weighted truck traffic (see Table 10). In addition, Table 11 presents the approximate mileage, by shoulder type, of those corridors analyzed. Figure 1 displays freeway and expressways and shoulder types in the corridors analyzed.

Homogeneous corridor segments (or partial segments) were also ranked comparing weighted total traffic, weighted truck traffic, total crash rates, and non-median non-roadway crash rates. Two ranking techniques were applied, rating of segments (and partial segments) both within specific corridors and statewide (see Table 12). Gray-shaded cells in Table 12 represent corridor segments with paved shoulders. These segments are included to preserve corridor continuity. Corridor segments (partial segments) with no current crash history were assigned a rating of 0. As data for these sections are compiled, a more accurate ranking can be calculated in the future. Corridor segments with granular shoulders and one or more years of crash history are also presented in Table 13. Average crash rates (non-intersection and non-median, non-roadway) were calculated for these segments. Above average crash rates are shaded in gray.

It may be noted that the route mileage totals in Table 10 may differ from the summation of lengths for individual segments in corresponding corridors in Table 12 or by shoulder type in Table 11. To simplify the analysis process, some short segments were eliminated where high variability in shoulder type and age of roadway was encountered. However, deletion of these segments in no way affected the accuracy of the rankings or other data presented in these tables.

Engineers and planners can use the information in these tables to aid in selecting possible candidates for shoulder improvements, considering the important factors of total traffic volumes, commercial vehicle numbers, and crash history. Other factors can also be of value in the prioritization and selection process including bicycle use, wide vehicle travel, continuity, and other specific local issues. Some of these topics will be addressed in the report recommendations.

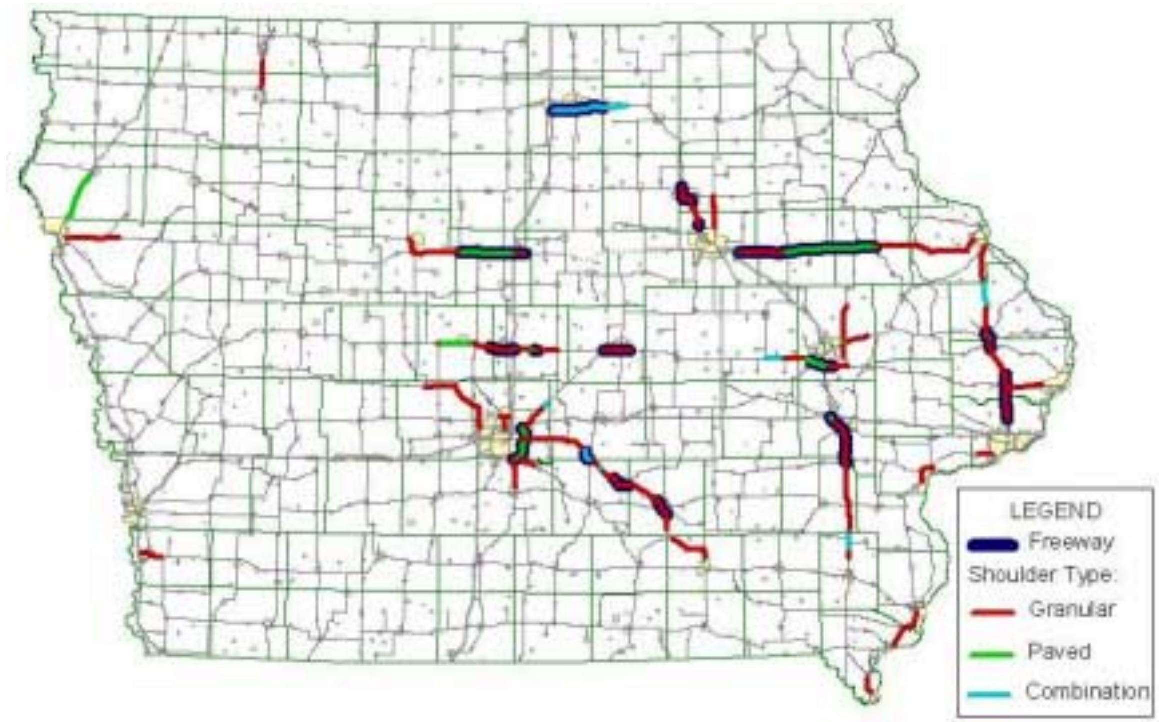

Figure 1. Four-Lane Rural Corridors (Segments Analyzed)

Table 10. AADT of Four-Lane Rural Corridors (Segments Analyzed)

Route	Length (miles)	Total Traffic		Truck Traffic	
		AADT	State Rank	AADT	State Rank
IA 160	1.0	12,000	1	347	17
IA 415	6.1	11,537	2	276	18
IA 141	26.7	11,378	3	842	10
US 65	31.8	11,045	4	976	8
IA 151	12.3	10,685	5	1,028	6
US 30	86.9	9,964	6	1,185	4
US 75	14.9	9,937	7	1,558	1
US 218	62.9	8,955	8	1,310	2
US 61	87.8	8,682	9	1,260	3
US 71	9.0	8,275	10	776	11
US 20	127.5	7,505	11	1,051	5
US 169	5.4	7,412	12	947	9
IA 163	57.1	7,395	13	980	7
US 34	7.1	7,306	14	474	14
IA 13	11.8	7,156	15	448	15
IA 5	5.4	8,116	16	464	16
US 63	29.0	5,915	17	739	12
US 18	23.8	3,998	18	681	13

Table 11. Mileage by Shoulder Type for Four-Lane Rural Corridors (Segments Analyzed)

Outside Shoulder Surface Type	Cumulative Length* (miles)
Paved	91.2
Granular	452.3
Combination**	45.4

*Total statewide mileage by shoulder type may vary slightly.
**Extended pavement surface (28 ft) with two 12-ft lanes and granular shoulders.

Table 12. AADT and Crash History of Corridor Segments

Location			Description			Traffic						Total Non-Intersection Crashes			Non-Roadway, Non-Median Crashes		
						Total			Truck								
Route	Begin	End	Shoulder Type	Length (miles)	Analysis Period (years)	AADT	Corr. Rank	State Rank	AADT	Corr. Rank	State Rank	Crash Rate (MVM)	Corr. Rank	State Rank	Crash Rate (MVM)	Corr. Rank	State Rank
IA 5	US 65	Carlisle	Granular	1.2	2	9,794	1	32	480	1	96	0.232	2	82	0.000	2	80
IA 5	Carlisle	End four-lane	Granular	3.0	1	6,658	2	79	441	2	98	0.685	1	17	0.137	1	15
IA 13	US 151	Central City	Granular	10.8	5	7,274	1	61	453	1	97	0.376	1	63	0.077	1	43
US 18	I-35	US 65	Combination*	6.8	0	4,136	1	99	771	1	78	0.000	0	0	0.000	0	0
US 18	US 65	Nora Springs	Combination*	9.2	0	3,930	3	102	661	2	87	0.000	0	0	0.000	0	0
US 18	Nora Springs	US 218	Combination*	7.5	0	4,006	2	101	631	3	88	0.000	0	0	0.000	0	0
US 20	Sioux City	Lawton	Granular	6.6	5	10,960	2	26	1,055	10	44	0.693	4	16	0.160	1	8
US 20	Lawton	End four-lane	Granular	8.2	5	7,113	9	66	899	12	63	0.783	1	8	0.151	3	10
US 20	End of four-lane	IA 17	Granular	15.0	5	5,767	13	90	1,420	4	20	0.594	7	26	0.126	4	20
US 20	IA 17	Webster City	Paved	2.4	5	7,197	8	64	1,421	3	19	0.411	12	58	0.095	8	32
US 20	Webster City	US 69	Paved	10.8	5	6,443	12	82	1,425	2	18	0.427	11	56	0.063	15	56
US 20	US 69	End four-lane	Granular	2.8	5	2,897	18	104	574	17	91	0.272	18	76	0.068	13	51
US 20	US 69	End four-lane	Paved	4.0	5	5,379	15	93	1,265	7	29	0.335	16	68	0.077	12	42
US 20	I-380	Jesup	Granular	6.0	5	8,872	6	40	729	13	81	0.484	10	47	0.082	10	37
US 20	Jesup	Independence	Granular	8.4	5	7,491	7	57	711	14	82	0.365	15	65	0.078	11	40
US 20	Independence	Winthorp	Paved	8.1	5	5,440	14	92	603	16	90	0.558	8	29	0.037	18	72
US 20	Winthorp	IA 187	Paved	4.3	5	4,983	16	94	574	18	92	0.334	17	69	0.103	6	28
US 20	IA 187	Manchester	Paved	10.2	5	4,940	17	95	627	15	89	0.370	14	64	0.054	16	61
US 20	Manchester	Delaware	Paved	5.3	5	6,718	11	77	992	11	49	0.778	2	10	0.092	9	34
US 20	Delaware	Dyersville	Granular	11.2	5	6,929	10	70	1,361	6	23	0.594	5	24	0.064	14	55
US 20	Dyersville	Farley	Granular	5.2	5	9,558	5	35	1,364	5	22	0.594	6	25	0.154	2	9
US 20	Farley	Epworth	Granular	4.2	5	9,772	4	33	1,179	8	35	0.386	13	60	0.053	17	63
US 20	Epworth	Peosta	Granular	4.6	5	10,529	3	29	1,146	9	38	0.507	9	39	0.113	5	24
US 20	Peosta	Dubuque	Granular	7.4	5	16,064	1	7	1,436	1	14	0.738	3	13	0.097	7	31
US 30	Ogden	Boone	Granular	0.9	5	4,710	16	96	425	16	100	0.401	9	59	0.000	13	80
US 30	Ogden	Boone	Paved	6.6	5	7,331	11	60	775	15	77	0.495	3	44	0.034	12	76
US 30	Boone	Ames (US 69)	Granular	11.6	5	12,028	6	17	990	10	50	0.318	12	72	0.051	9	65
US 30	Boone	Ames (US 69)	Paved	3.5	5	10,813	7	27	840	14	69	0.430	8	55	0.057	6	60
US 30	Ames	Nevada	Granular	7.0	5	15,719	3	8	1,235	6	31	0.323	11	71	0.065	4	53

Location			Description			Traffic						Total Non-Intersection Crashes			Non-Roadway, Non-Median Crashes		
						Total			Truck								
Route	Begin	End	Shoulder Type	Length (miles)	Analysis Period (years)	AADT	Corr. Rank	State Rank	AADT	Corr. Rank	State Rank	Crash Rate (MVM)	Corr. Rank	State Rank	Crash Rate (MVM)	Corr. Rank	State Rank
US 30	Ames	Nevada	Paved	0.4	5	12,462	5	15	1,139	9	40	0.698	1	15	0.000	13	80
US 30	Nevada	US 65 (Colo)	Granular	7.8	4	6,918	14	72	863	13	66	0.485	5	46	0.064	5	54
US 30	IA 330	End four-lane	Granular	8.5	3	6,927	13	71	935	11	60	0.452	6	52	0.047	10	67
US 30	US 218	IA 151	Combination*	6.0	0	6,916	15	73	1,141	8	39	0.000	0	0	0.000	0	0
US 30	US 218	IA 151	Granular	6.4	5	9,531	8	36	1,266	5	28	0.306	13	74	0.036	11	73
US 30	US 218	IA 151	Paved	2.9	5	7,016	12	67	1,188	7	33	0.189	15	85	0.054	7	62
US 30	IA 151	I-380	Paved	4.0	5	16,502	2	5	2,147	2	3	0.382	10	61	0.100	2	30
US 30	I-380	IA 13	Granular	5.4	5	14,740	4	9	2,067	3	4	0.493	4	45	0.075	3	45
US 30	I-380	IA 13	Paved	1.2	5	18,556	1	1	2,396	1	1	0.230	14	83	0.051	8	64
US 30	IA 13	End four-lane	Granular	0.6	5	8,657	9	44	865	12	65	0.447	7	53	0.000	13	80
US 30	US 61	Clinton	Granular	12.5	5	8,059	10	49	1,314	4	27	0.497	2	43	0.115	1	23
US 34	I-29	IA 385	Granular	3.5	5	7,941	1	52	513	1	94	0.718	1	14	0.140	1	13
US 34	IA 385	US 275	Granular	3.6	5	6,669	2	78	433	2	99	0.526	2	37	0.069	2	48
US 61	S. Jct. US 218	N. Jct. US 218	Granular	5.2	5	8,708	7	43	1,338	7	25	0.475	10	48	0.061	10	58
US 61	Ft Madison	IA 16	Granular	2.0	3	8,259	8	47	954	14	57	0.216	13	84	0.000	13	80
US 61	Ft Madison	IA 16	Granular	4.7	5	8,155	9	48	953	15	58	1.009	1	3	0.216	2	4
US 61	IA 16	Burlington	Granular	6.3	3	9,300	6	38	1,063	9	43	0.917	3	5	0.187	3	5
US 61	Muscatine bypass		Granular	7.6	5	12,204	3	16	1,700	3	7	0.590	7	27	0.041	12	71
US 61	Blue Grass	I-280	Granular	3.8	4	11,757	5	22	1,699	4	8	0.418	12	57	0.046	11	68
US 61	I-80	Long Grove	Granular	2.0	5	17,299	1	4	1,928	1	5	0.625	5	20	0.063	9	57
US 61	Long Grove	US 30	Granular	7.9	5	14,062	2	10	1,828	2	6	0.618	6	21	0.119	6	22
US 61	US 30	Welton	Granular	3.7	3	7,702	10	55	1,257	8	30	0.769	4	11	0.288	1	2
US 61	US 30	Welton	Granular	2.6	5	6,797	11	75	1,349	6	24	0.978	2	4	0.126	5	19
US 61	Welton	Maquoketa	Granular	1.1	1	4,287	16	98	809	16	72	0.000	0	0	0.000	0	0
US 61	Welton	Maquoketa	Granular	10.6	3	6,555	12	81	1,042	10	45	0.461	11	49	0.079	8	39
US 61	Maquoketa	Zwingle	Combination*	7.3	0	5,800	15	89	1,030	11	46	0.000	0	0	0.000	0	0
US 61	Maquoketa	Zwingle	Granular	7.8	5	5,837	14	88	1,028	13	48	0.072	14	90	0.000	13	80
US 61	Zwingle	US 151	Granular	8.2	2	5,922	13	87	1,029	12	47	0.562	8	28	0.112	7	26
US 61	US 151	US 52	Granular	2.8	5	11,904	4	19	1,587	5	11	0.536	9	36	0.179	4	6
US 63	Waterloo	IA 3	Granular	10.1	5	7,187	3	65	914	2	61	0.781	1	9	0.113	3	25
US 63	Oskaloosa	Eddyville	Granular	3.0	1	7,200	2	63	978	1	51	0.636	2	19	0.127	2	18
US 63	Eddyville	IA 149	Granular	11.0	2	3,806	4	103	509	4	95	0.262	4	78	0.131	1	17
US 63	IA 149 (end four-lane)	Ottumwa	Granular	2.5	5	7,259	1	62	562	3	93	0.508	3	38	0.030	4	78
US 65	Indianola	Des Moines	Granular	8.9	5	16,495	1	6	821	4	71	0.546	1	32	0.090	1	35
US 65	I-80	IA 163	Paved	4.2	5	11,336	2	25	1,445	1	13	0.183	3	86	0.046	3	69

Location			Description			Traffic						Total Non-Intersection Crashes			Non-Roadway, Non-Median Crashes		
						Total			Truck								
Route	Begin	End	Shoulder Type	Length (miles)	Analysis Period (years)	AADT	Corr. Rank	State Rank	AADT	Corr. Rank	State Rank	Crash Rate (MVM)	Corr. Rank	State Rank	Crash Rate (MVM)	Corr. Rank	State Rank
US 65	IA 163	IA 5	Paved	6.0	2	9,521	3	37	800	5	73	0.000	0	0	0.000	0	0
US 65	I-80	End four-lane	Combination*	1.4	0	7,900	5	54	1,208	2	32	0.000	0	0	0.000	0	0
US 65	US 69	IA 5	Paved	2.4	2	6,252	6	83	381	6	101	0.000	4	91	0.000	4	80
US 65	I-80	End four-lane	Granular	7.9	5	8,391	4	46	1,172	3	36	0.240	2	81	0.066	2	52
US 71	Spencer	Fostoria	Granular	3.9	5	8,648	1	45	776	1	75	0.540	1	34	0.033	2	77
US 71	Fostoria	Arnolds Park	Granular	5.1	5	7,982	2	50	776	1	75	0.432	2	54	0.135	1	16
US 75	Sioux City	Hinton	Paved	4.8	5	10,728	1	28	1,602	2	10	0.607	2	23	0.170	2	7
US 75	Hinton	Merrill	Paved	6.0	5	9,900	2	31	1,611	1	9	0.507	3	40	0.120	3	21
US 75	Merrill	Le Mars	Paved	4.1	5	9,057	3	39	1,429	3	16	0.848	1	6	0.223	1	3
IA 141	I-35/I-80	IA 17	Granular	8.1	5	18,095	1	3	1,132	1	41	0.358	2	66	0.049	3	66
IA 141	IA 17	IA 210	Granular	6.8	2	8,845	3	41	711	2	83	0.114	5	88	0.069	2	49
IA 141	IA 17	IA 210	Granular	1.5	5	10,008	2	30	706	3	84	0.248	4	80	0.035	4	75
IA 141	IA 210	Perry	Granular	5.0	2	7,553	5	56	693	5	86	0.611	1	22	0.072	1	46
IA 141	IA 210	Perry	Granular	4.9	5	7,903	4	53	694	4	85	0.342	3	67	0.014	5	79
IA 151	US 30	US 151	Granular	3.1	2	12,600	1	13	1,182	1	34	0.284	3	75	0.036	3	74
IA 151	US 30	US 151	Granular	1.1	4	12,570	2	14	1,156	2	37	0.554	1	30	0.101	2	29
IA 151	US 30	US 151	Granular	8.1	5	9,727	3	34	954	3	56	0.536	2	35	0.104	1	27
IA 160	IA 415	US 69	Granular	1.0	5	12,000	1	18	347	1	103	0.682	1	18	0.000	1	80
IA 163	Pleasant Hill	IA 117	Granular	1.5	1	8,741	2	42	1,066	2	42	1.017	1	2	0.407	1	1
IA 163	Pleasant Hill	IA 117	Granular	12.7	5	11,453	1	23	1,321	1	26	0.380	2	62	0.072	3	47
IA 163	IA 117	IA 14	Combination*	4.2	0	5,989	9	86	740	11	80	0.000	0	0	0.000	0	0
IA 163	IA 117	IA 14	Granular	3.8	1	6,597	7	80	967	3	52	0.000	0	0	0.000	0	0
IA 163	IA 117	IA 14	Granular	3.0	3	6,773	6	76	780	9	74	0.180	6	87	0.000	5	80
IA 163	IA 14	IA 102	Combination*	0.9	0	6,025	8	85	837	8	70	0.000	0	0	0.000	0	0
IA 163	IA 14	IA 102	Combination*	2.1	0	6,902	5	74	958	4	54	0.000	0	0	0.000	0	0

Location			Description			Traffic						Total Non-Intersection Crashes			Non-Roadway, Non-Median Crashes		
						Total			Truck								
Route	Begin	End	Shoulder Type	Length (miles)	Analysis Period (years)	AADT	Corr. Rank	State Rank	AADT	Corr. Rank	State Rank	Crash Rate (MVM)	Corr. Rank	State Rank	Crash Rate (MVM)	Corr. Rank	State Rank
IA 163	IA 14	IA 102	Granular	6.7	3	7,000	3	68	958	4	54	0.331	3	70	0.078	2	41
IA 163	IA 14	IA 102	Granular	5.8	5	4,671	10	97	905	6	62	0.262	4	77	0.061	4	59
IA 163	IA 102	IA 92	Granular	12.6	1	6,959	4	69	884	7	64	0.251	5	79	0.000	5	80
IA 163	IA 92	US 63	Granular	3.1	2	2,431	11	105	752	10	79	0.000	0	0	0.000	0	0
US 169	US 20	IA 7	Granular	5.4	5	7,412	1	59	947	1	59	1.130	1	1	0.068	1	50
US 218	Cedar Falls	Janesville	Granular	2.8	4	11,800	4	21	850	7	67	0.454	6	50	0.000	7	80
US 218	Cedar Falls	Janesville	Granular	2.0	5	11,898	3	20	850	7	67	0.316	7	73	0.000	7	80
US 218	Janesville	IA 431	Granular	7.5	1	4,056	9	100	354	9	102	0.806	1	7	0.090	4	36
US 218	Janesville	IA 431	Granular	3.6	5	13,337	2	11	961	6	53	0.507	4	41	0.081	5	38
US 218	I-80	IA 1	Granular	5.2	5	18,123	1	2	2,275	1	2	0.548	2	31	0.146	2	12
US 218	IA 1	IA 22	Granular	10.1	5	11,356	5	24	1,509	2	12	0.541	3	33	0.139	3	14
US 218	IA 22	IA 92	Granular	13.7	2	7,972	6	51	1,428	4	17	0.501	5	42	0.150	1	11
US 218	IA 92	Olds (IA 78)	Granular	10.8	1	5,571	8	91	1,384	5	21	0.091	8	89	0.045	6	70
US 218	IA 78	Mt. Pleasant	Granular	5.4	1	6,136	7	84	1,431	3	15	0.000	0	0	0.000	0	0
IA 415	Des Moines	IA 160	Granular	4.1	5	13,021	1	12	292	1	104	0.744	1	12	0.093	1	33
IA 415	End of four-lane	IA 160	Granular	1.8	5	7,444	2	58	212	2	105	0.453	2	51	0.075	2	44

*Extended pavement surface (28 ft) with two 14-ft lanes and granular shoulders.
Note: Gray-shaded cells represent corridor segments with paved shoulders.

Table 13. Crash Rates on Corridor Segments with Granular Shoulders

Location			Description		Non-Intersection Crash Rate (MVM) *Avg: 0.505*	Non-Roadway, Non-Median Crash Rate (MVM) *Avg: 0.088*
Route	Begin	End	Length (miles)	Analysis Period (years)		
US 169	US 20	IA 7	5.4	5	1.130	0.068
IA 163	Pleasant Hill	IA 117	1.5	1	1.017	0.407
US 61	Ft Madison	IA 16	4.7	5	1.009	0.216
US 61	US 30	Welton	2.6	5	0.978	0.126
US 61	IA 16	Burlington	6.3	3	0.917	0.187
US 218	Janesville	IA 431	7.5	1	0.806	0.090
US 20	Lawton	End four-lane	8.2	5	0.783	0.151
US 63	Waterloo	IA 3	10.1	5	0.781	0.113
US 61	US 30	Welton	3.7	3	0.769	0.288
IA 415	Des Moines	IA 160	4.1	5	0.744	0.093
US 20	Peosta	Dubuque	7.4	5	0.738	0.097
US 34	I-29	IA 385	3.5	5	0.718	0.140
US 20	Sioux City	Lawton	6.6	5	0.693	0.160
IA 5	Carlisle	End four-lane	3.0	1	0.685	0.137
IA 160	IA 415	US 69	1.0	5	0.682	0.000
US 63	Oskaloosa	Eddyville	3.0	1	0.636	0.127
US 61	I-80	Long Grove	2.0	5	0.625	0.063
US 61	Long Grove	US 30	7.9	5	0.618	0.119
IA 141	IA 210	Perry	5.0	2	0.611	0.072
US 20	End of four-lane	IA 17	15.0	5	0.594	0.126
US 20	Delaware	Dyersville	11.2	5	0.594	0.064
US 20	Dyersville	Farley	5.2	5	0.594	0.154
US 61	Muscatine bypass		7.6	5	0.590	0.041
US 61	Zwingle	US 151	8.2	2	0.562	0.112
IA 151	US 30	US 151	1.1	4	0.554	0.101
US 218	I-80	IA 1	5.2	5	0.548	0.146
US 65	Indianola	Des Moines	8.9	5	0.546	0.090
US 218	IA 1	IA 22	10.1	5	0.541	0.139
US 71	Spencer	Fostoria	3.9	5	0.540	0.033
US 61	US 151	US 52	2.8	5	0.536	0.179
IA 151	US 30	US 151	8.1	5	0.536	0.104
US 34	IA 385	US 275	3.6	5	0.526	0.069
US 63	IA 149 (end four-lane)	Ottumwa	2.5	5	0.508	0.030
US 20	Epworth	Peosta	4.6	5	0.507	0.113
US 218	Janesville	IA 431	3.6	5	0.507	0.081
US 218	IA 22	IA 92	13.7	2	0.501	0.150
US 30	US 61	Clinton	12.5	5	0.497	0.115
US 30	I-380	IA 13	5.4	5	0.493	0.075
US 30	Nevada	US 65 (Colo)	7.8	4	0.485	0.064
US 20	I-380	Jesup	6.0	5	0.484	0.082
US 61	S. Jct. US 218	N. Jct. US 218	5.2	5	0.475	0.061
US 61	Welton	Maquoketa	10.6	3	0.461	0.079
US 218	Cedar Falls	Janesville	2.8	4	0.454	0.000
IA 415	End of four-lane	IA 160	1.8	5	0.453	0.075
US 30	IA 330	End four-lane	8.5	3	0.452	0.047
US 30	IA 13	End four-lane	0.6	5	0.447	0.000
US 71	Fostoria	Arnolds Park	5.1	5	0.432	0.135
US 61	Blue Grass	I-280	3.8	4	0.418	0.046
US 30	Ogden	Boone	0.9	5	0.401	0.000
US 20	Farley	Epworth	4.2	5	0.386	0.053
IA 163	Pleasant Hill	IA 117	12.7	5	0.380	0.072
IA 13	US 151	Central City	10.8	5	0.376	0.077
US 20	Jesup	Independence	8.4	5	0.365	0.078
IA 141	I-35/I-80	IA 17	8.1	5	0.358	0.049
IA 141	IA 210	Perry	4.9	5	0.342	0.014
IA 163	IA 14	IA 102	6.7	3	0.331	0.078

Location			Description		Non-Intersection Crash Rate (MVM) *Avg: 0.505*	Non-Roadway, Non-Median Crash Rate (MVM) *Avg: 0.088*
Route	**Begin**	**End**	**Length (miles)**	**Analysis Period (years)**		
US 30	Ames	Nevada	7.0	5	0.323	0.065
US 30	Boone	Ames (US 69)	11.6	5	0.318	0.051
US 218	Cedar Falls	Janesville	2.0	5	0.316	0.000
US 30	US 218	IA 151	6.4	5	0.306	0.036
IA 151	US 30	US 151	3.1	2	0.284	0.036
US 20	US 69	End four-lane	2.8	5	0.272	0.068
US 63	Eddyville	IA 149	11.0	2	0.262	0.131
IA 163	IA 14	IA 102	5.8	5	0.262	0.061
IA 163	IA 102	IA 92	12.6	1	0.251	0.000
IA 141	IA 17	IA 210	1.5	5	0.248	0.035
US 65	I-80	End four-lane	7.9	5	0.240	0.066
IA 5	US 65	Carlisle	1.2	2	0.232	0.000
US 61	Ft Madison	IA 16	2.0	3	0.216	0.000
IA 163	IA 117	IA 14	3.0	3	0.180	0.000
IA 141	IA 17	IA 210	6.8	2	0.114	0.069
US 218	IA 92	Olds (IA 78)	10.8	1	0.091	0.045
US 61	Maquoketa	Zwingle	7.8	5	0.072	0.000
US 61	Welton	Maquoketa	1.1	1	0.000	0.000
IA 163	IA 117	IA 14	3.8	1	0.000	0.000
IA 163	IA 92	US 63	3.1	2	0.000	0.000
US 218	IA 78	Mt. Pleasant	5.4	1	0.000	0.000

Note: Gray-shaded cells represent above average crash rates.

SUPPLEMENTAL BENEFITS

Numerous studies conducted in other states have documented reduced crash rates, improved capacities, lessened maintenance effort, and even better pavement performance resulting from fully or partially paved shoulders. Some of these desirable effects can also be achieved with increased lane widths and this criterion has been successfully implemented in Iowa for four-lane and Super 2 highway designs. However, additional potential benefits from paved shoulders can also be perceived.

These advantages include more available travel width for wide loads, especially those that require permitting. These drivers often must steer onto roadway shoulders when meeting opposing traffic, resulting in reduced stability for the vehicle and dislodging of material from granular shoulders. Likewise, off-tracking by commercial vehicles, particularly on horizontal curves and at intersections, can cause shoulder degradation and displacement of granular material onto the paved road surface, reducing contact friction for other road users.

Operators of slow-moving farm equipment are often reluctant to travel even partially on granular shoulders. This practice can increase traffic queuing and the potential of collisions following these vehicles, especially where passing opportunities are hindered by terrain, road geometrics, and high traffic volume. An increased width of paved roadway surface can fully or, at least partially, address these issues.

Paved shoulders can offer a significant benefit for bicyclists. AASHTO's *Guide for the Development of Bicycle Facilities* (*37*) and the Federal Highway Administration's *Selecting Roadway Design Treatments to Accommodate Bicycles* (*38*) are excellent reference sources for bicycle accommodation on roads. Both of these documents recommend minimum four to six foot wide paved shoulders for bicycle travel on rural highways where significant use in anticipated. The wider design would be recommended with higher traffic volume and coincident use of rumble strips adjacent to the traveled way for motorized vehicles. The state transportation plan, *Iowa in Motion* (*39*), envisions a strong need for increased accommodation of bicycle and pedestrian traffic over the next 20 years. Much of this anticipated need must be met with on-road improvements. In addition, Iowa's recently proposed Trails Program includes approximately 4,900 miles of Vision Corridors for specific bicycle adaptation. Almost 1,800 miles of this future network follows existing primary highway routes. The road segments included in the Visions Corridors network will provide excellent bicycle accommodation with paved shoulders. Establishing a systematic program for paving shoulders in the Visions Corridors network would demonstrate Iowa's commitment to high quality bicycle accommodation in the state.

Strong public support for more paved shoulders was indicated by a recent survey conducted by the Center for Social and Behavioral Research at the University of Northern Iowa. Results from that scientific poll revealed that almost 70 percent of Iowans would support an expanded program for paving shoulders with rumble strips on all roadways.

CONCLUSIONS AND RECOMMENDATIONS

The value of providing paved shoulders adjacent to higher volume roadways has been accepted in many states across the country. Benefits to road user safety in reducing the numbers of certain crashes, higher capacity potential, reduced maintenance, enhanced opportunities for other users such as bicyclists, and even possible increased longevity of pavements have all been attributed to paved shoulders in numerous studies and research reports. Based on the information gained through analysis of these research results, other states design practices, and general available literature on the subject, the following conclusions have been drawn and recommendations offered for consideration in the state of Iowa.

Conclusions

1. A significant amount of national research has found benefits of paved shoulders on four-lane and many classes of two-lane rural roads. Most benefits were described in terms of reduced associated crash rates and less necessary maintenance.

2. In general, effective value from paved shoulders can be obtained with a minimum width of two to three feet. For road sections with significant bicycle usage, a minimum width of four feet is suggested. Wider paved shoulders may not be cost effective except with very high-volume roadways or special categories such as the interstate system.

3. Many national studies also found significant value from the use of rumble strips with paved shoulders to reduce run-off-road incidence.

4. States surrounding Iowa specify a minimum two to three foot wide paved shoulder adjacent to all four-lane and many two-lane rural roads. These design criteria apply to both new construction and 3R improvements.

5. A significant reduction in maintenance costs can be realized through increased paved shoulder use, up to $366 per mile per year for a two-lane road.

6. Reduced crash rates with paved shoulders found in many studies could not be verified with confidence in Iowa, a finding that may be attributable to the relatively few miles of non-interstate rural Iowa roads with paved shoulders that are available for comparison. Thus, valid crash data on comparable routes for comparative analysis are not available, particularly on two-lane highways.

7. Iowa may be realizing many benefits of paved shoulders from the 14-foot-wide outside lane of four-lane and 26-foot-wide Super 2 pavement widths, resulting in an effective 2-foot-wide paved shoulder surface adjacent to traffic lanes.

Recommendations

1. The Iowa Department of Transportation should consider design standard modifications adopting three-foot minimum width paved shoulders adjacent to the outside lanes of four-lane rural freeways and expressways for new construction. Widening of initial paving width to 27 feet should be considered as an option. Paved shoulders for median lanes could be considered with special criteria such as exceptionally high commercial vehicle usage.

2. For existing four-lane freeways and expressways with 26-foot-wide pavement, widening to achieve a three-foot-wide paved shoulder could be accomplished with future 3R improvements, when needed.

3. Minimum width three-foot-wide paved shoulders should be added to design criteria for Super 2 roadways. Specifying a 30-foot initial paving width should be considered to accomplish this ultimate roadway section.

4. For primary road sections that warrant further bicycle accommodation, including but not limited to sections designated as part of Iowa's Visions Corridors, four to six-foot minimum width paved shoulders should be considered. Based on design recommendations from both AASHTO and FHWA for rumble strips in paved shoulders, a six-foot width would seem appropriate when significant bicycle use is anticipated.

5. All paved shoulder installations should include rumble strips to discourage run-off-road incidence by road users, but potential impacts on bicyclists should be considered in the design.

6. Ranking tables provided in this report can be used to prioritize eligible shoulder paving candidates on a district or state level.

7. Shoulder paving to minimum effective widths can be considered with new construction, 3R projects, or, when justified, as stand-alone improvements.

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APPENDIX A: COMPARATIVE IMPROVEMENT AND MAINTENANCE COSTS

The following improvement costs are from Iowa DOT year 2000 average bid prices. Costs of excavation, subbase, traffic control, and miscellaneous are not included.

- Paved shoulder, PCC, eight-inch thick: $27.37/s.y.
- Paved shoulder, ACC, Type B, eight-inch thick: $15.19/s.y.
- Granular shoulder, Type B, 8-inch thick: $11.53/ton or $3.80/s.y.
- Standard or slip form PCC, Class C, Class 3 durability, 10-inch thick: $26.56/s.y.

Initial shoulder materials (two-lane) cost comparisons are as follows:

- Paved shoulder, 3-foot width: 3,520 s.y./mile @ $15.19/s.y. = $53,469/mile (ACC)
- Paved shoulder, 4-foot width: 4,693 s.y./mile @ $15.19/s.y. = $71,287/mile (ACC)
- Paved shoulder, 6-foot width: 7,040 s.y./mile @ $15.19/s.y. = $106,938/mile (ACC)
- Granular shoulder, 3-foot width: 3,520 s.y./mile @ $3.80/s.y. = $13,376/mile
- Granular shoulder, 4-foot width: 4,693 s.y./mile @ $3.80/s.y. = $17,833/mile
- Granular shoulder, 6-foot width: 7,040 s.y./mile @ $3.80/s.y. = $26,752/mile
- Widened pavement lanes: $15,431/mile/foot of widening (PCC pavement)

Overlay costs for shoulder restoration from Iowa DOT 1997 design estimates are as follows:

- Three-inch ACC overlay: $6.53/s.y.
- Three-inch granular material: $3.41/s.y.

Overlay costs for shoulder restoration from prorated Iowa DOT 2000 bid prices are as follows:

- Three-inch ACC overlay: $5.69/s.y.
- Three-inch granular material: $1.43/s.y.

Maintenance functions for paved shoulders include repair with bituminous material, sealing edge ruts, filling shoulder joints, and other paved shoulder repairs. For FY 1996–2000, Iowa DOT statewide maintenance costs for paved shoulders (4,304 lane-miles) averaged $329,000/year or about $76/lane-mile.

Maintenance functions for granular shoulders include repair with aggregate and blading. For FY 1996–2000, Iowa DOT statewide maintenance costs for granular shoulders (18,483 lane-miles) averaged $4,794,000/year or about $259/lane-mile.

The maintenance cost savings for paved vs. granular shoulders total approximately $366/mile/year for a two-lane road. Over a 20-year life, these savings would total approximately $7,320/mile.

APPENDIX B: PAVED SHOULDER ALTERNATIVES

Table B.1. Alternative Paved Shoulder Width Standards

	Total Shoulder Width/Shoulder Width Paved		
	Freeway/Expressway		Super Two
	Right	Left	
Alternative 1	10 ft/10 ft	6 ft/6 ft	10 ft/10 ft
Alternative 2	10 ft/6 ft	6 ft/6 ft	10 ft/6 ft
Alternative 3	10 ft/4 ft	6 ft/2 ft	10 ft/4 ft
Existing	10 ft/2 ft	6 ft/0 ft	10 ft/2 ft

Note: All proposed standards assume a "full depth" eight-inch-thick ACC paved shoulder.

Table B.2. Incremental Cost Assessments of Paved Shoulder Alternatives

	Incremental Cost (per mile)			
	Current	Alternative 1	Alternative 2	Alternative 3
New expressway, four lane	$3,000,000	$3,187,000	$3,134,000	$3,054,000
3R for expressway, four lane	$400,000	$650,000	$580,000	$470,000
Reconstructed Super 2	$2,000,000	$2,107,000	$2,054,000	$2,027,000

Table B.3. Cost to Replace Granular Shoulders on Existing Freeway/Expressway System (500 miles)

	Rate Calculation	Total Cost
Alternative 1	500 at $250,000/mile	$125,000,000
Alternative 2	500 at $180,000/mile	$90,000,000
Alternative 3	500 at $72,000/mile	$36,000,000

Table B.4. Alternative 1 (Full-Width Paved Shoulders) FY 2003–2005 Impact

	Miles	Incremental Per Mile Cost	Additional Program Cost
New Construction ($11.39/s.y.):			
Four-lane	134	$187,000	$25,058,000
Two on four-lane	96	$94,000	$9,024,000
Super 2	18	$107,000	$1,926,000
Subtotal			$36,008,000
3R Program Retrofit ($15.19/s.y.):			
Four-lane 3R	98	$250,000*	$24,500,000
Two on four-lane 3R	104	$125,000*	$13,000,000
Subtotal			$37,500,000
Total			$73,508,000

*Assumes total paved shoulder thickness of eight inches, including overlay. Does not include cost of excavation, traffic control, and mobilization.

Table B.5. Alternative 2 (Six-Foot-Wide Paved Shoulders) FY 2003–2005 Impact

	Miles	Incremental Per Mile Cost	Additional Program Cost
New Construction: ($11.39/s.y.):			
Four-lane	134	$134,000	$18,090,000
Two on four-lane	96	$67,000	$6,432,000
Super 2	18	$54,000	$972,000
Subtotal			$25,494,000
3R Program Retrofit ($15.19/s.y.):			
Four-lane 3R	98	$180,000*	$17,640,000
Two on four-lane 3R	104	$90,000*	$9,360,000
Subtotal			$27,000,000
Total			$52,494,000

*Assumes total paved shoulder thickness of eight inches, including overlay. Does not include cost of excavation, traffic control, and mobilization.

Table B.6. Alternative 3 (Four-Foot-Wide Paved Shoulders)* FY 2003–2005 Impact

	Miles	Incremental Cost	Additional Program Cost
New Construction ($11.39/s.y.):			
Four-lane	134	$54,000	$7,236,000
Two on four-lane	96	$27,000	$2,592,000
Super 2	18	$27,000	$486,000
Subtotal			$10,314,000
3R Program Retrofit ($15.19/s.y.):			
Four-lane 3R	98	$72,000**	$7,056,000
Two on four-lane 3R	104	$36,000**	$3,744,000
Subtotal			$10,800,000
Total			$21,114,000

*Except two-foot-wide inside (left) paved shoulder on freeway/expressways.

**Assumes total paved shoulder thickness of eight inches, including overlay. Does not include cost of excavation, traffic control, and mobilization.