Measuring Performance of Innovative Pavement Features

Wayne Jensen
University of Nebraska-Lincoln, wayne.jensen@unl.edu

Zhigang Shen
University of Nebraska - Lincoln, shen@unl.edu

Cody Kluver
Mechanical Systems, Inc.

Measuring Performance of Innovative Pavement Features

Wayne Jensen, Ph.D., PE; Zhigang Shen, Ph.D. & Cody Kluver, B.S., CM

ABSTRACT

The Nebraska Department of Roads (NDOR) conducts annual examinations of the state's interstate and federal highway pavements. During these examinations, numerous indicators of pavement performance are measured directly or compiled from parameters recorded by a vehicle passing over the pavement section. Parameters are documented and analyzed for each one-tenth mile pavement segment. Seven sections where innovative features have been incorporated into the pavement were selected by the NDOR for comparison to nearby conventional pavement sections. This study used various parameters recorded by the NDOR as well as field observations to compare the performance of seven pairs of pavement sections. Each pair contained one section of pavement with innovative features and a second section of more conventional design.

Pavement performance indicators measured and analyzed included Nebraska Serviceability Index, International Roughness Index, Present Serviceability Index, cracking index, rutting and faulting, plus longitudinal and transverse cracking. The study indicates that pavement sections that had innovative features incorporated generally performed better than pavement sections where more conventional design was used.

Keywords: pavement performance, longitudinal cracking, digital photography, bituminous materials

INTRODUCTION

Several innovative pavement features have been introduced into the State highway system by the Nebraska Department of Roads during the past decade. These technologies include

Wayne Jensen, Ph.D., PE

Wayne G. Jensen is an Associate Professor in the Construction Management and Civil Engineering Departments at the University of Nebraska Lincoln. He has a M.S. and Ph.D. in civil engineering from the University of Wyoming and 21 years of construction experience with the U.S. Army Corps of Engineers.

Zhigang Shen, Ph.D.

Zhigang Shen is an Assistant Professor in the Department of Construction Management at the University of Nebraska–Lincoln. Dr. Shen received his B.E. and M.S. degrees in Architecture from China, plus a M.S. in computer engineering and Ph.D. in construction management from the University of Florida. He has seven years of building industry experience in both U.S. and China on a variety of the world class projects.

Cody Kluver, B.S., CM

Cody Kluver received a B.S. degree in Construction Management from the University of Nebraska–Lincoln in May of 2008. He is currently working as a project manager for Mechanical Systems, Inc., a commercial HVAC contractor in Omaha, NE.

1. initial placement of or retrofitting of dowel bars into pavement transverse joints;
2. continuous "day lighting" of granular sub base material for drainage;
3. lime and fly ash modified sub grades;
4. longitudinal tining of concrete pavement;
5. Portland cement concrete overlays of milled asphalt pavement; and
6. crumb rubber asphalt overlays.

The Pavement Quality Indicators (PQI) study was initiated in 2003 with the objective of analyzing the performance of pavement sections with innovative features and comparing their performance to that exhibited by similar, more conventional pavement sections.

Seven pavement sections where innovative technologies were incorporated and selected by the NDOR for comparison to nearby conventional pavement sections. Close geographic proximity (of each matched pair) was essential to establish similar environmental conditions and nearly identical traffic loads. The geographic distribution of the pavement sections in this study is illustrated in ***Figure 1—Map showing seven original and three new pavement locations*** (next page).

Pavement performance indicators regularly analyzed by the NDOR include Present Serviceability Index (PSI), cracking index, faulting index, International Roughness Index (IRI), and rutting (FHWA, 2003). Some indices, including the Nebraska Serviceability Index for both concrete and asphalt pavements, were developed and are used only within the State of Nebraska (NDOR, 2002). Since this study began, several of the conventional concrete pavement sections have been retrofitted with dowel bars. These sections remained in the study at least through the five year report. Within the last year, three additional innovative sections (Plattsmouth West, Republican City and Malmo Spur West) and two additional comparison sections (Louisville East and Alma–Republican City) were added. The sections recently added will allow analysis of incorporating fly ash as a stabilization agent into bituminous materials and study the effects of incorporating recycled asphalt into leveling/wearing courses or pavement subgrades.

This study utilized information collected by the NDOR as part of their annual pavement evaluation studies and included site visits to all pavement sections on an annual basis. Site visits were documented by measuring various physical parameters as well as by digital photography. Comparing digital photography over time often vividly illustrates distress suggested by analysis of quality data.

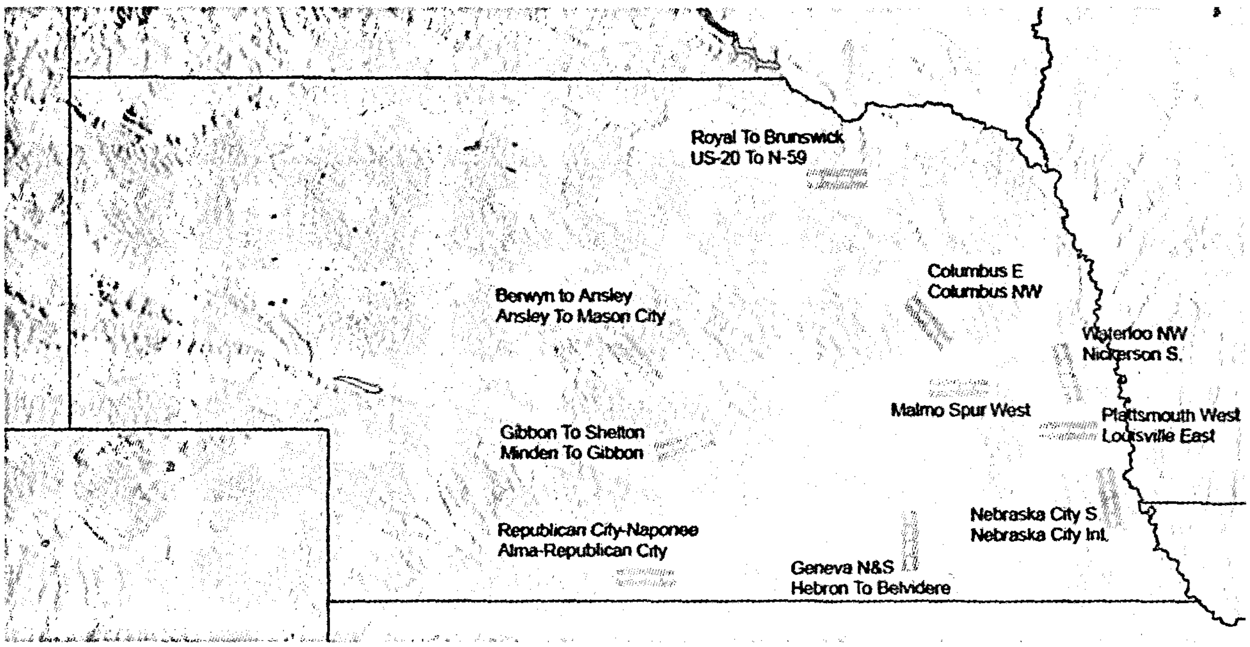

Figure 1. Map showing seven original and three new pavement locations

HOW THE NDOR MANAGES PAVEMENT QUALITY

The NDOR conducts annual examinations of Nebraska's interstate and federal highway pavements. During these examinations, numerous indicators of pavement performance are measured directly or are compiled from parameters recorded by a vehicle passing over the pavement section. Parameters are documented and analyzed for each one-tenth mile segment. This study used data recorded by the NDOR as well as field observations to develop a standardized comparison of performance between two paired pavement sections. Information about the pavement performance indicators discussed in the next paragraphs will be referenced throughout this report. The performance indicators measured and the conditions of each which relate to various levels of service are discussed below (NDOR, 2008).

Nebraska Serviceability Index (NSI): Overall surface condition of pavement rated by a pavement evaluator on a subjective scale of 0–100. The same range of numbers in used for bituminous pavement (NSI BIT) and Portland cement concrete (NSI PCC).

Very good:	90 & Over
Good:	70–89
Fair:	50–69
Poor:	30–49
Very Poor:	0–29

International Roughness Index (IRI): Pavements smoothness is measured as vertical millimeters per lateral meter (mm/m).

Very smooth:	0.0–0.85
Smooth:	0.86–2.48
Moderately rough:	2.49–3.33
Rough:	3.34–4.21
Very Rough:	4.22 & Over

Present Serviceability Index (PSI): An AASHTO index indicating the functional ability of the pavement to serve the public, based on roughness, with a rating of 5 being best and 0 worst.

Very Good:	4.1–5.0
Good:	3.1–4.0
Fair:	2.1–3.0
Poor:	1.1–2.0
Very Poor:	0.0–1.0

Cracking Index: Approximate percentage of bituminous surfacing (BIT) that is cracked or the percentage of PCC (Portland Cement Concrete) panels which are cracked.

Acceptable:	0–30
Tolerable:	30–50
Unacceptable:	over 50

Rutting: Average rut depth for a bituminous surface expressed in millimeters (mm).

Acceptable:	Less than 6
Tolerable:	6–13
Unacceptable:	Over 13

Faulting: The amount of displacement between two adjacent slabs measured at the common joint or structural crack in millimeters (mm). Pavement with faulting in excess of 6 mm is considered poor quality.

Longitudinal Cracking: Longitudinal cracking denotes cracks that run predominantly parallel to the centerline. These cracks may be in the wheel paths, between wheel paths and/or at lane joints such as along the centerline or shoulder.

Table 1. Innovative and conventional paired pavement sections

		Locations	Pavement Features	Foundation Course Features	Subbase Features	Evaluated Performance Indicators
	Innovative	Waterloo Northwest	25 cm dowelled PCC		10 cm granular drained	Faulting and
Pair 1	Conventional	Nickerson South	25 cm non-dowelled PCC		conventional	Smoothness
	Innovative	Nebraska City South	25 cm doweled PCC	10 cm daylighted	lime stabilized	Faulting and
Pair 2	Conventional	Nebraska City Interchange	25 cm non-doweled PCC	10 cm non-daylighted	conventional	Smoothness
	Innovative	Columbus East	25 cm doweled PCC	10 cm day-lighted	fly ash stabilized	Faulting and
Pair 3	Conventional	Columbus NW	25 cm of dowel bar retrofitted PCC	10 cm non-daylighted	conventional	PCC NSI
	Innovative	Geneva NS	25 cm doweled PCC	10 cm daylighted	lime treated	
Pair 4	Conventional	Hebron to Belvidere	25 cm dowel bar retrofitted PCC	10 cm non-daylighted	bituminous	Faulting and PSI
	Innovative	Gibbon to Shelton	10 cm crumb rubber modified asphalt			
Pair 5	Conventional	Minden to Gibbon	10 cm (Superpave 4) asphalt			BIT NSI and IRI
	Innovative	US-20 to N-59	5 cm crumb rubber modified asphalt surface course over a 3.5 cm (Superpave 1) leveling course			BIT NSI and
Pair 6	Conventional	Royal to Brunswick	10 cm (Superpave 2) asphalt			Rutting Depth
	Innovative	Berwyn to Ansley	20 cm doweled concrete overlay		milled asphalt	Faulting and NSI
Pair 7	Conventional	Berwyn to Ansley	22.5 cm non-doweled PCC		conventional	PCC Index

Transverse Cracking: Cracks that run perpendicular to centerline, resulting in a panel that is broken into two or more pieces. Panels broken into two pieces are rated Class I and panels broken into more than two pieces are rated Class II.

METHODS

Fourteen total pavement sections were selected by the NDOR to examine performance, over a multiyear period, of the innovative versus conventional pavement designs. The innovative features of newer pavement sections plus specific design details of the conventional sections are summarized in ***Table 1.***

RESULTS

When considering age related distresses, graphing data by calendar year does not allow comparison based upon the true age of pavement unless the pavements were constructed in the same calendar year. All comparisons in this study were graphed based upon chronological age of pavement when various parameters were measured, versus the year in which the measurement was taken. This process allowed for more accurate comparison of age related distress at nearly identical points in each pavement's lifespan.

Results of this study consist of comparisons of parameters for seven innovative versus conventional pavement sections. Only some of the most significant data is included in this paper. The final report for this study (Kluver and Jensen, 2008) is seventy pages in length and contains significant digital photography which was not included in this paper.

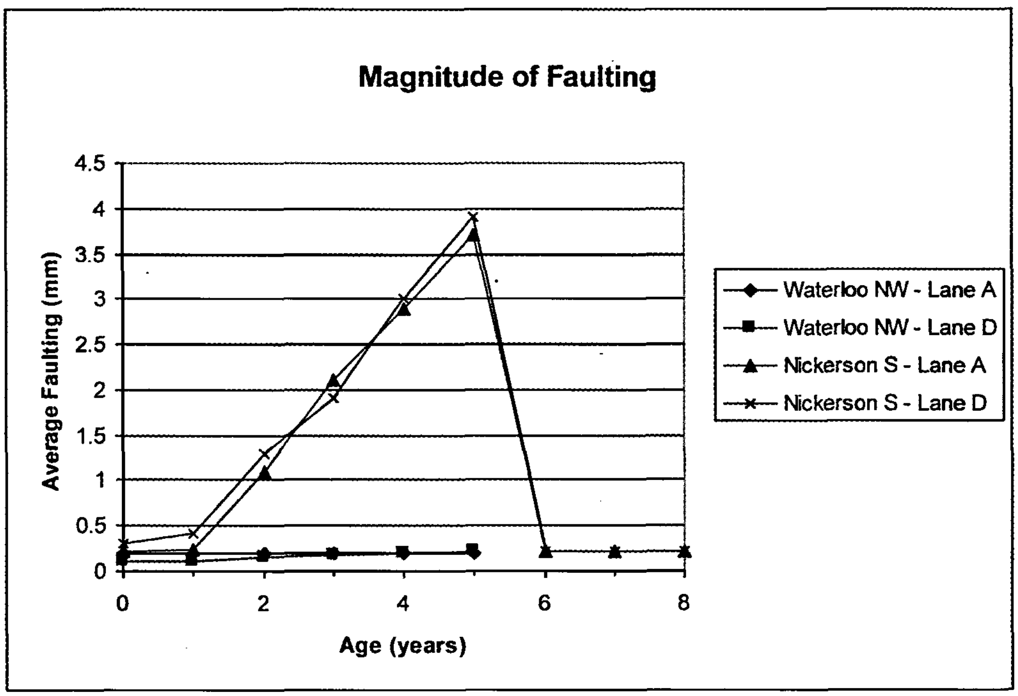

Figure 2. Magnitude of faulting for doweled and non-doweled PCC pavement

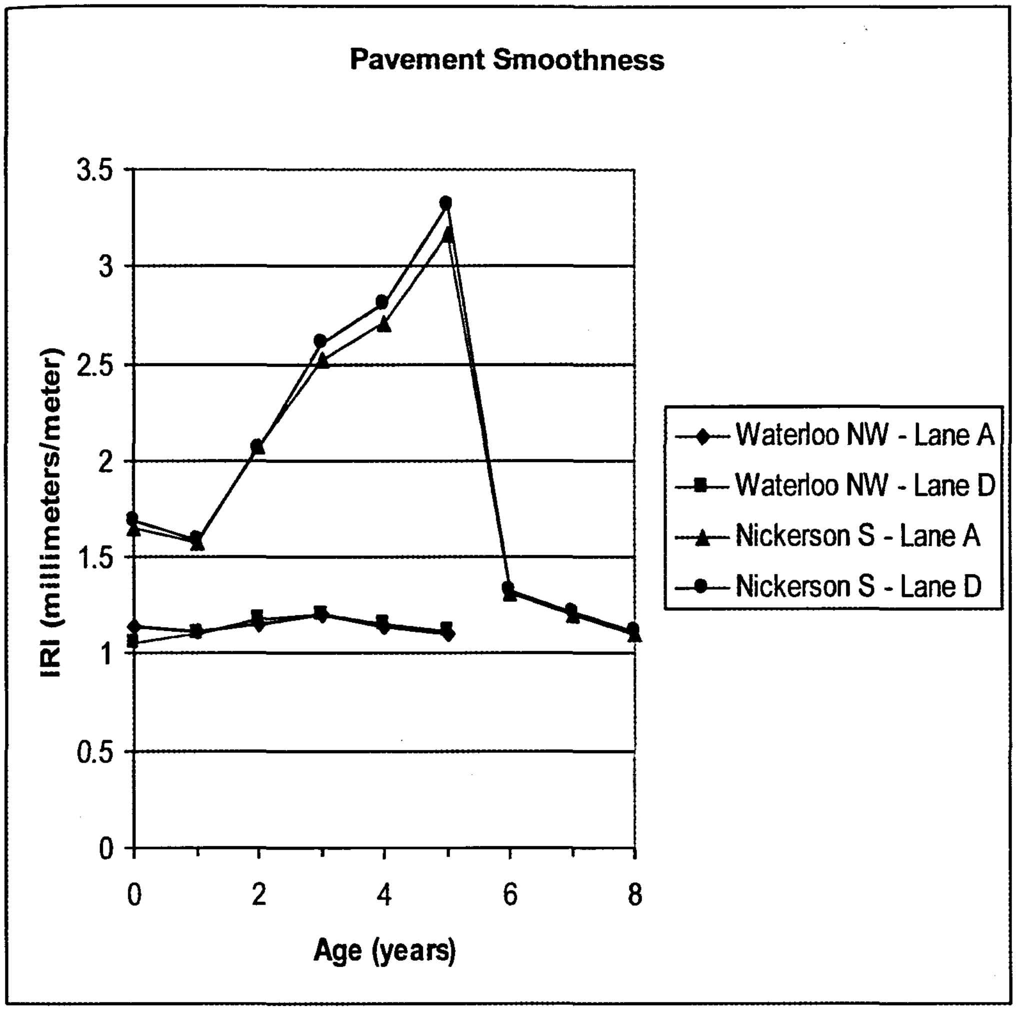

Figure 3. IRI of doweled and non-doweled PCC pavement

WATERLOO NW COMPARED TO NICKERSON SOUTH

Figure 2—Magnitude of faulting for doweled and non-doweled PCC pavement (previous page) shows how the use of dowel bars in the Waterloo Northwest section has limited faulting during the first five years. Figure 2 also shows the benefits of dowel bar retrofitting non-doweled PCC pavement sections. Nickerson South was dowel bar retrofitted after year five, which when coupled with milling, resulted in pavement with faulting levels similar to new pavement. There was also a significant decrease in the rate of faulting. Nickerson South's initial trend over the first five years showed a steady increase in faulting to nearly three millimeters (half the allowable maximum) by the end of year five. After the dowel bar retrofit, Nickerson South had an almost negligible increase in the rate of faulting.

Figure 3—IRI of doweled and non-doweled PCC pavement.

The dowelled Waterloo Northwest pavement has remained much smoother than the non-doweled Nickerson South pavement. At the end of a five year period, the conventional section was rated, by the International Roughness Index, as moderately rough. Once retro-fitted with dowel bars and milled, Nickerson South approached the Waterloo Northwest section in smoothness. The rate of increase in roughness decreased from approximately 0.3 mm/m per year before thedowel bar retrofit to a negligible value after the retrofit was completed.

NEBRASKA CITY SOUTH VERSUS NEBRASKA CITY INTERCHANGE

Figure 4—Faulting for PCC over lime stabilized subgrade and drainable foundation course versus PCC over conventional subgrade without drainage (next page).

The dowelled pavement sections (Nebraska City South) have performed better with respect to faulting than the non-dowelled (Nebraska City Interchange) section. At the end of year nine, the non-doweled pavement exhibits faulting of about three and one-half millimeters while the doweled section exhibits faulting of only about one millimeter after four years. If current trends continue, a drainable foundation course over lime stabilized subgrade can be expected to halve the faulting expected with more conventional PCC pavement design.

Figure 5—IRI for PCC over lime stabilized subgrade and drainable foundation course versus PCC over conventional subgrade without drainage (next page).

Over the past four years, the doweled pavement has shown very little increase in IRI (less than 0.5 mm/m) while the conventional section showed a steady increase averaging about 0.1 mm/m/year) over nine years. If current trends continue, a drainable foundation course over lime stabilized sub grade can be expected to maintain an approximate new level of smoothness versus increasing in roughness similar to more conventional PCC pavement design.

COLUMBUS EAST VERSUS COLUMBUS NORTHWEST

Figure 6—Faulting for doweled PCC pavement over fly ash stabilized subgrade versus dowel bar retrofitted pavement over conventional subgrade (next page).

Columbus Northwest, originally a non-doweled section, experienced a steady increase in the level of faulting, averaging 0.6 mm/m/year, and culminating in an average of three millimeters after six years. The level and rate of faulting significantly decreased after a dowel bar retrofit with milling was performed on the Columbus Northwest section in the seventh year. While Columbus Northwest has seen a slow increase in the level of faulting in recent year, the rate of increase is much less than prior to the dowel bar retrofit. The

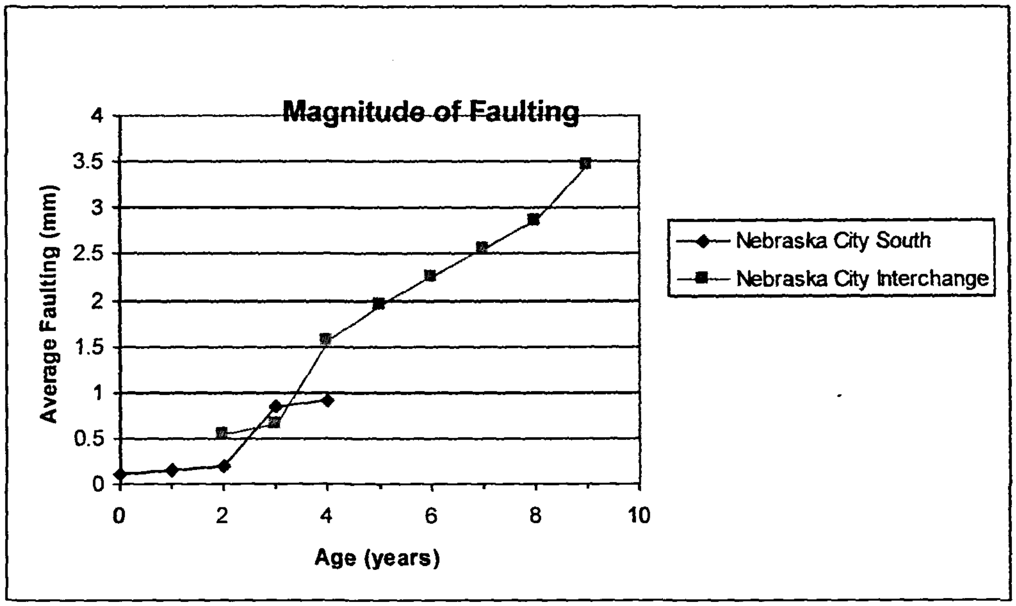

Figure 4. Faulting for PCC over lime stabilized subgrade and drainable foundation course versus PCC over conventional subgrade without drainage

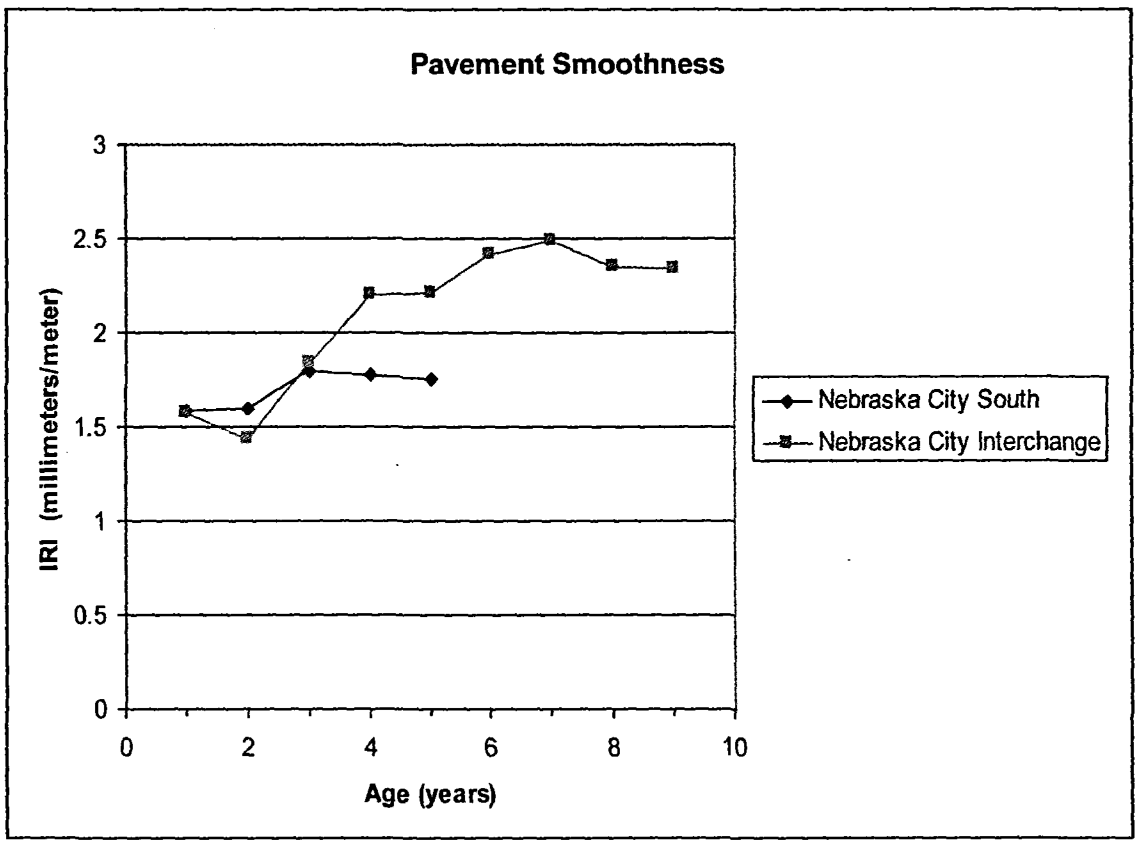

Figure 5. IRI for PCC over lime stabilized subgrade and drainable foundation course versus PCC over conventional subgrade without drainage

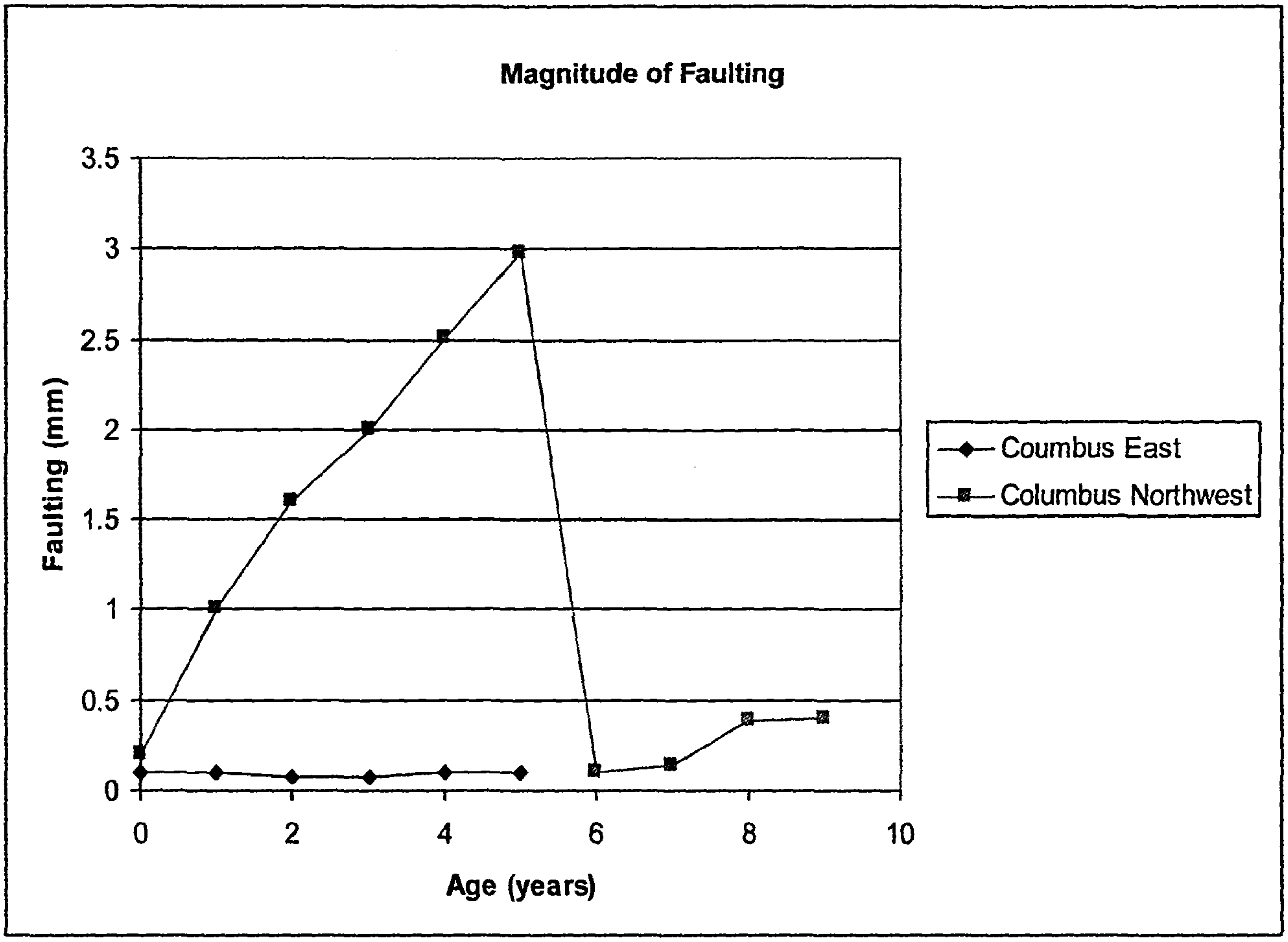

Figure 6. Faulting for doweled PCC pavement over fly ash stabilized subgrade versus dowel bar retrofitted pavement over conventional subgrade

Columbus East (doweled) section has recorded an almost negligible level of faulting since its construction five years ago.

Figure 7—NSI for doweled PCC pavement over fly ash stabilized subgrade versus dowel bar retrofitted pavement over conventional subgrade (next page).

Figure 7 (next page) shows how the Columbus Northwest section was affected by a dowel bar retrofit at the end of year six. After the retrofit, the Nebraska Serviceability Index increased to 98 then began decreasing at an accelerating rate. This decrease was at least partially caused by placing the retrofitted dowel bars too close to the shoulders, thereby causing the pavement corners to crack in both panels at each transverse joint near the shoulders. Outside dowel bars now being placed are located six inches closer to the centerline to mitigate this problem.

GENEVA NORTH AND SOUTH VERSUS HEBRON TO BELVIDERE

Figure 8—Faulting for doweled PCC pavement with lime treated subgrade and drainable foundation course compared to dowel bar retrofitted pavement with a bituminous foundation course (next page).

The dowelled Geneva North and South section has outperformed the non-dowelled conventional section with regard to faulting. A dowel bar retrofit after year six of the Hebron to Belvidere section has resulted in faulting almost identical to that found when dowel bars were emplaced during new pavement construction. The dowelled Geneva North and South section has shown little to no faulting after four years.

Figure 9—PSI for doweled PCC pavement with lime treated subgrade and drainable foundation course compared to dowel bar retrofitted PCC pavement with a bituminous foundation course.

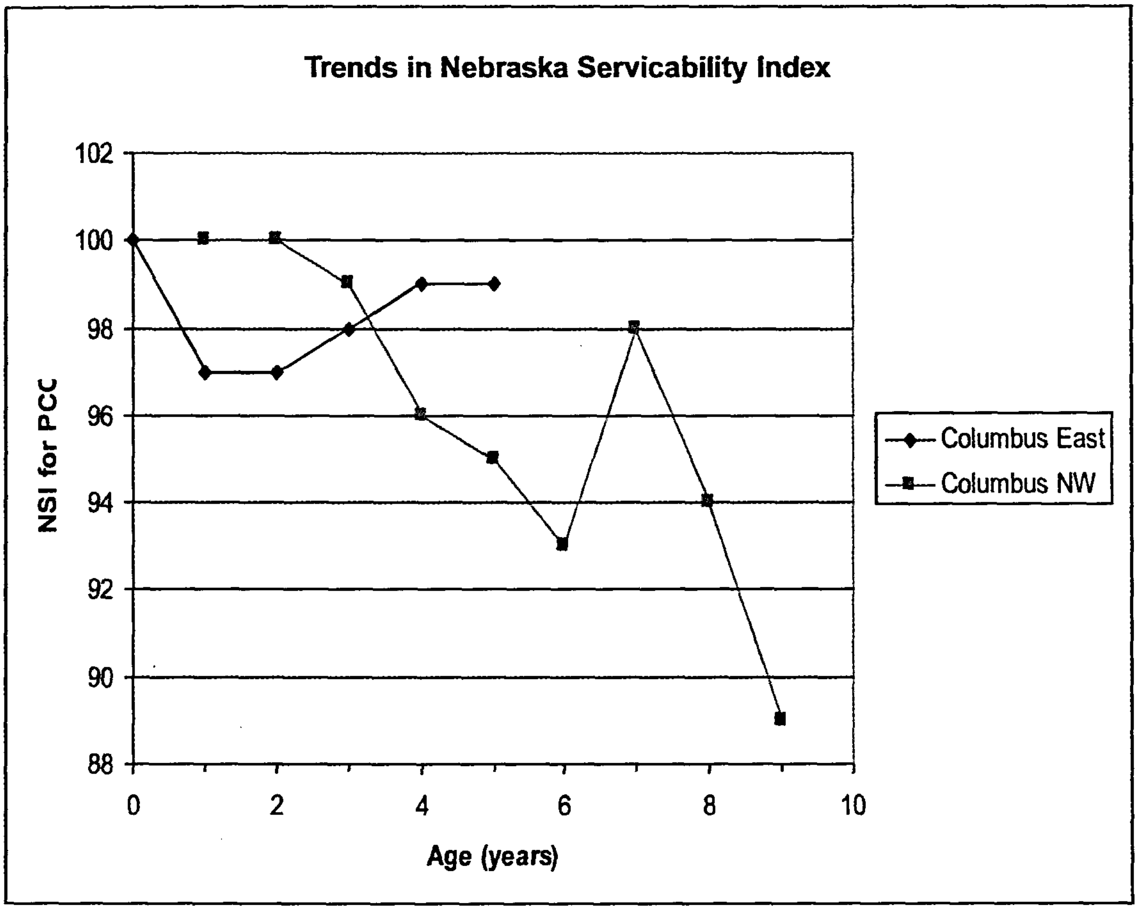

Figure 7. NSI for doweled PCC pavement over fly ash stabilized subgrade versus

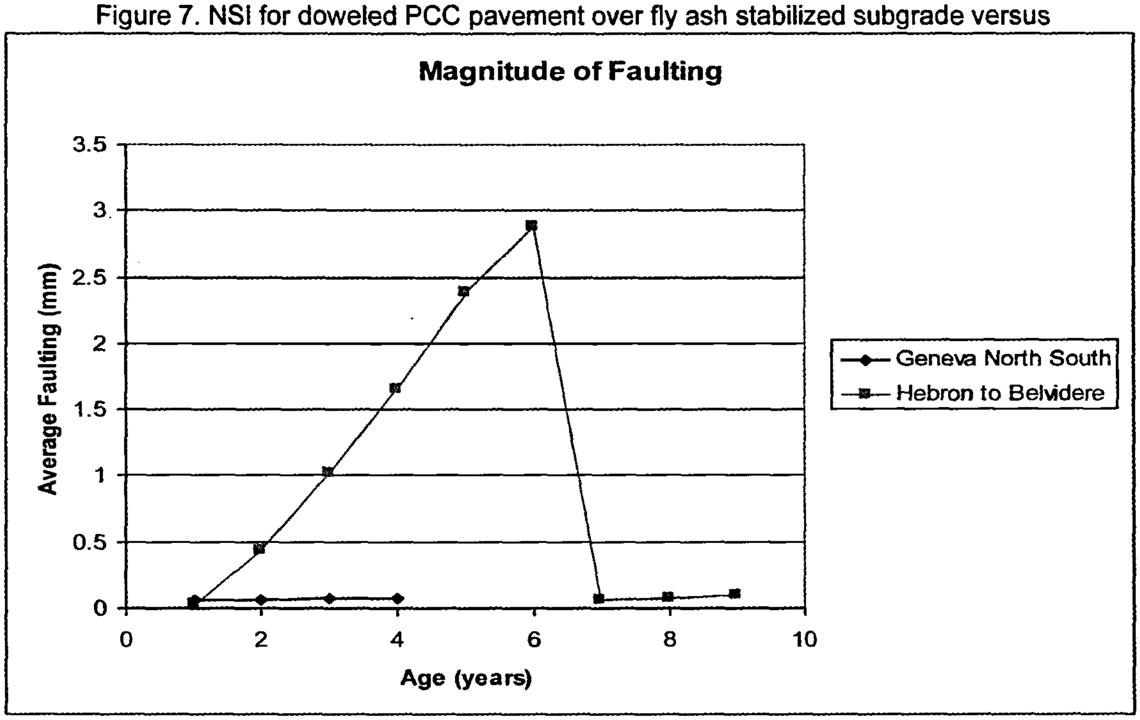

Figure 8. Faulting for doweled PCC pavement with lime treated subgrade and drainable foundation course compared to dowel bar retrofitted pavement with a bituminous foundation course

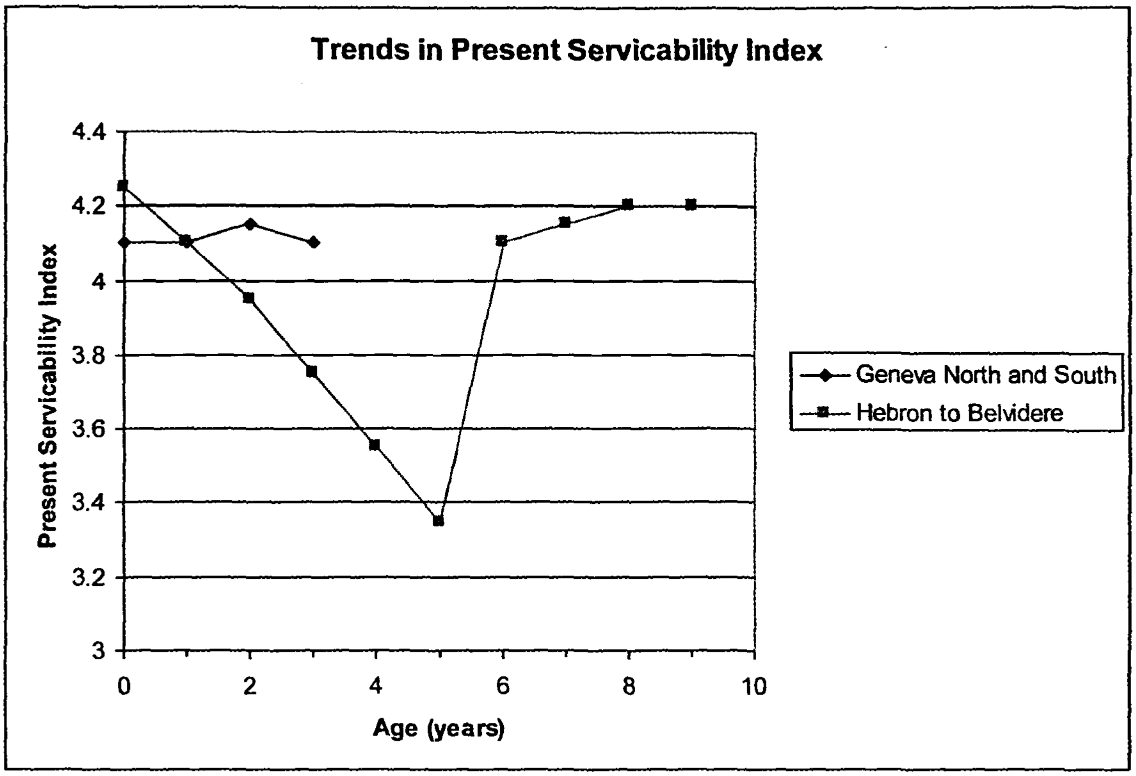

Figure 9. PSI for doweled PCC pavement with lime treated subgrade and drainable foundation course compared to dowel bar retrofitted PCC pavement with a bituminous foundation course

The PSI for the innovative pavement section has changed little over four years. After five years, the PSI for the conventional pavement section had steadily decreased from a very good to a good rating. If that trend were allowed to continue, the PSI for Hebron to Belvidere would have decreased to a fair or poor rating within a few years. The dowel bar retrofit after year five increased the PSI to a level similar to that found in the innovative pavement section.

GIBBON TO SHELTON VERSUS MINDEN TO GIBBON

Figure 10—NSI bituminous index for crumb rubber modified versus Superpave 4 asphalt (next page).

Crumb rubber modified (CRM) asphalt performed almost identically to Superpave 4 asphalt over the first four years on this interstate section. During the fifth year, the surface condition of CRM asphalt decreased much more rapidly than did the surface condition of the Superpave asphalt.

Figure 11—IRI for crumb rubber modified versus Superpave 4 asphalt (next page).

The crumb rubber modified and Superpave 4 asphalt sections behaved very similarly with respect to IRI during the first four years of each pavement's lifespan. There appears to be little difference between the two pavements with regard to smoothness during the first four years.

US-20 TO N-59

Figure 12—Rutting depth crumb rubber modified compared to Superpave 2 asphalt pavement (page 15).

The crumb rubber modified asphalt on US20 to N59 shows far less magnitude of rutting than the Superpave 2 asphalt pavement on Royal to Brunswick. Superpave 2 asphalt has a rate of (rut) depth increase of approximately three millimeters per year while the CRM asphalt shows little to no increase in either rate or magnitude of rutting.

Figure 13—NSI bituminous index of crumb rubber modified compared to Superpave 2 asphalt pavement (page 15).

The crumb rubber modified asphalt (US20 to N59) has consistently maintained a NSI bituminous index near 100 while the Superpave 2 asphalt has steadily decreased from a value of ninety to sixty after six years. If the Royal to Brunswick section continues to decline at its current rate, replacement will be required in approximately three years.

BERWYN TO ANSLEY VERSUS ANSLEY TO MASON CITY

Figure 14—Faulting magnitude for concrete overlay on asphalt compared to conventional PCC pavement (page 16).

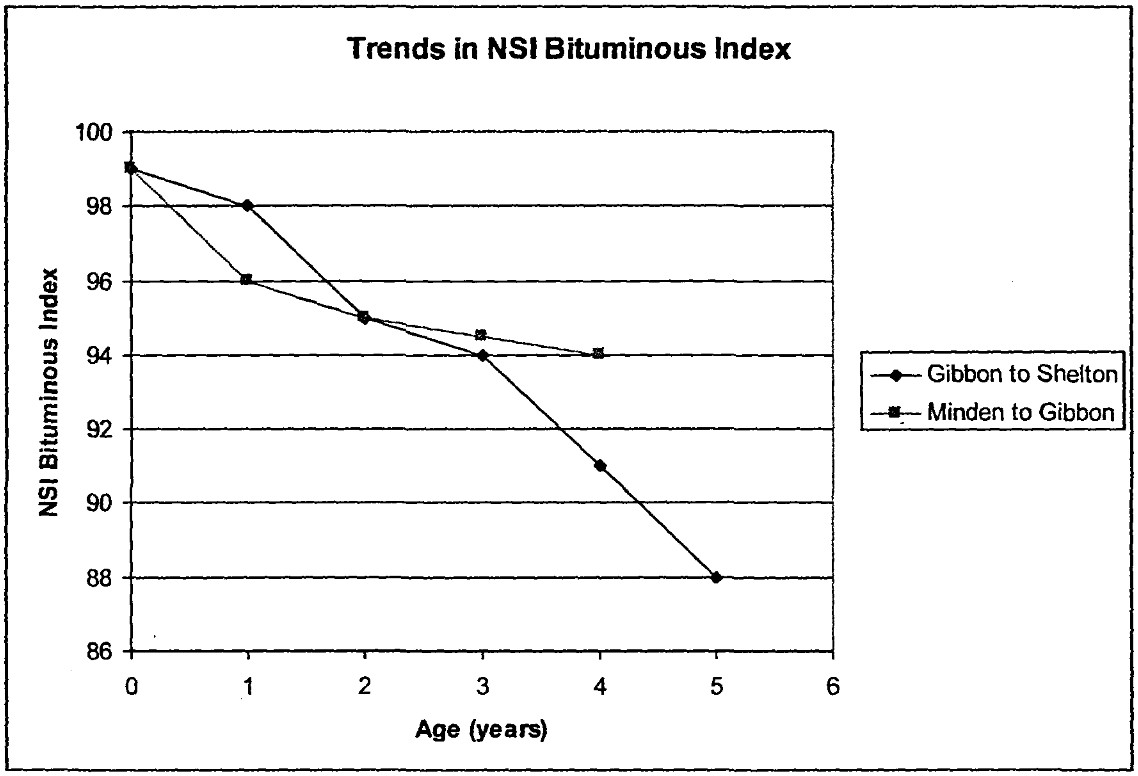

Figure 10. NSI bituminous index for crumb rubber modified versus Superpave 4 asphalt

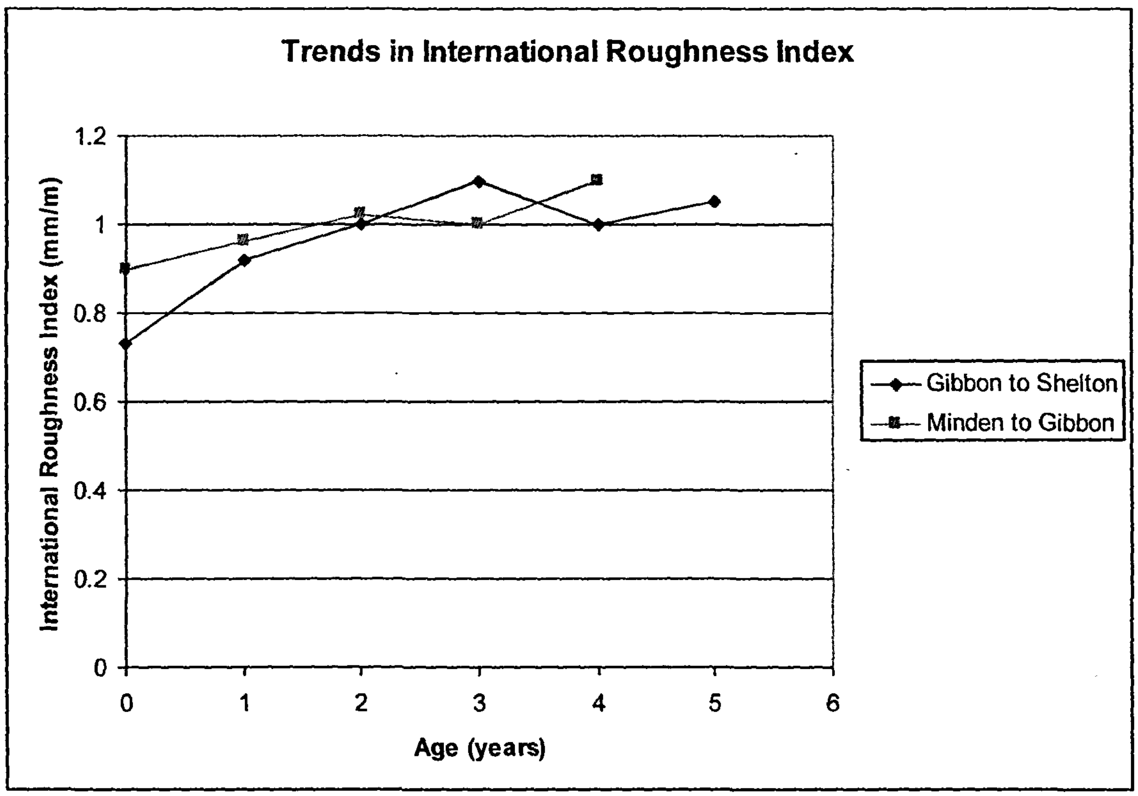

Figure 11. IRI for crumb rubber modified versus Superpave 4 asphalt

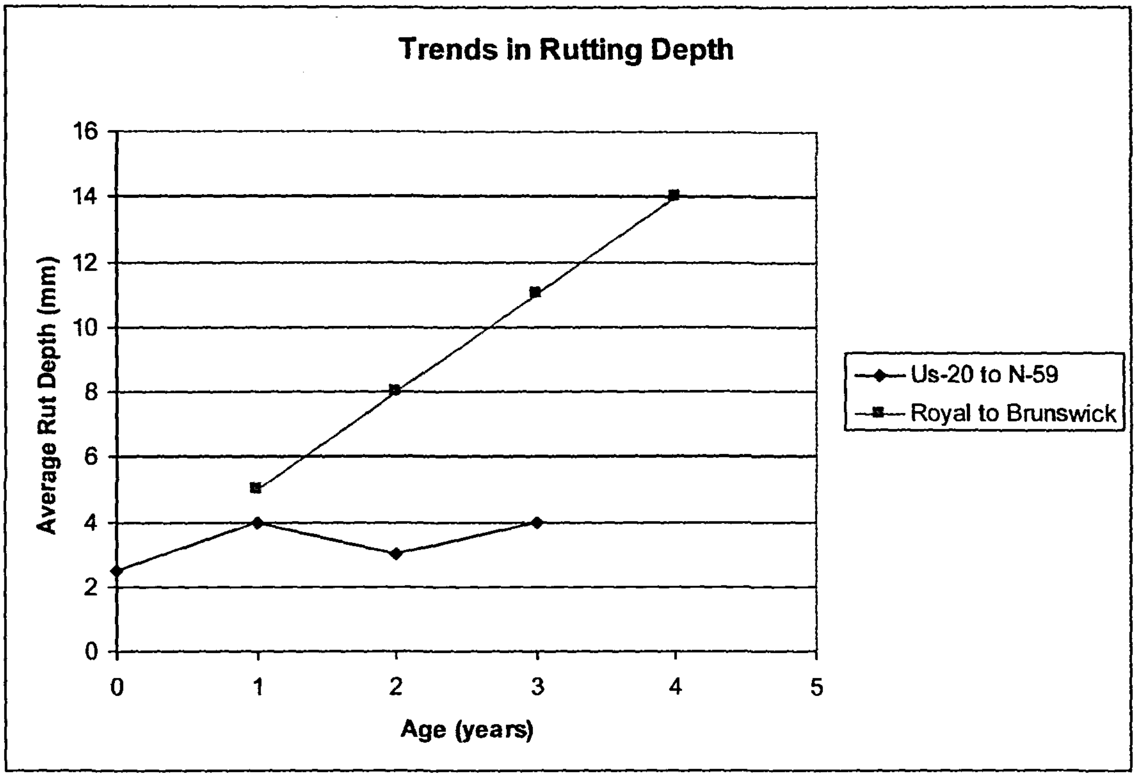

Figure 12. Rutting depth crumb rubber modified compared to Superpave 2 asphalt pavement

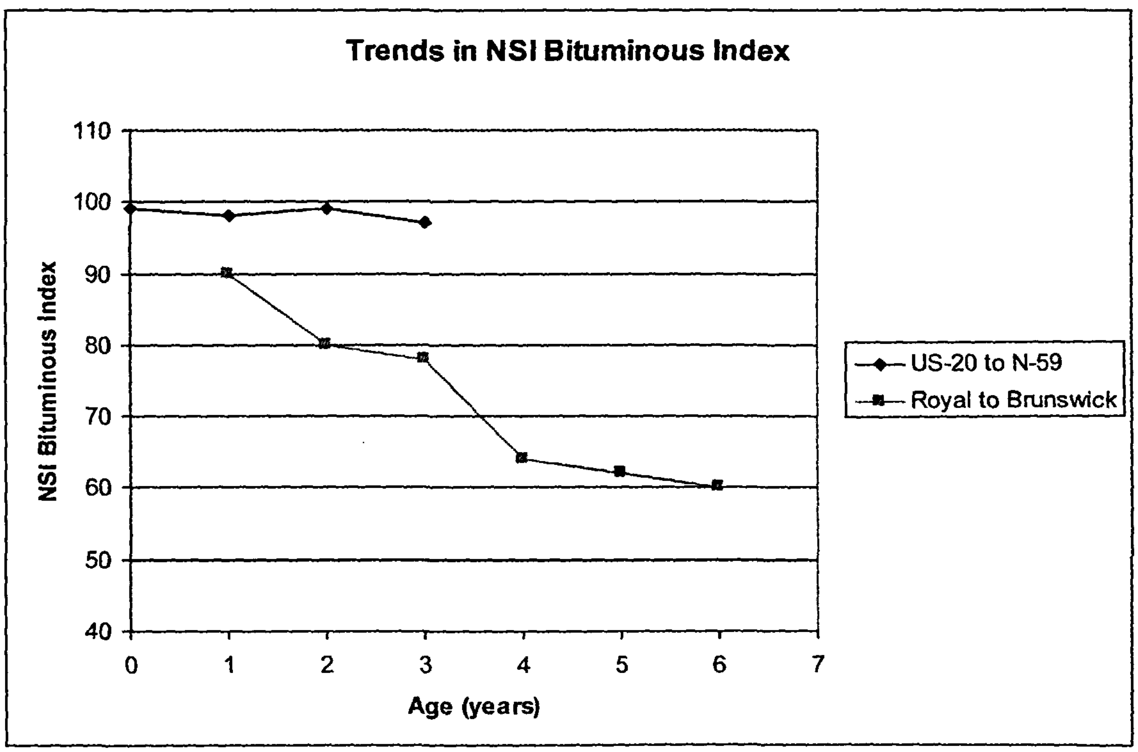

Figure 13. NSI bituminous index of crumb rubber modified compared to Superpave 2 asphalt pavement

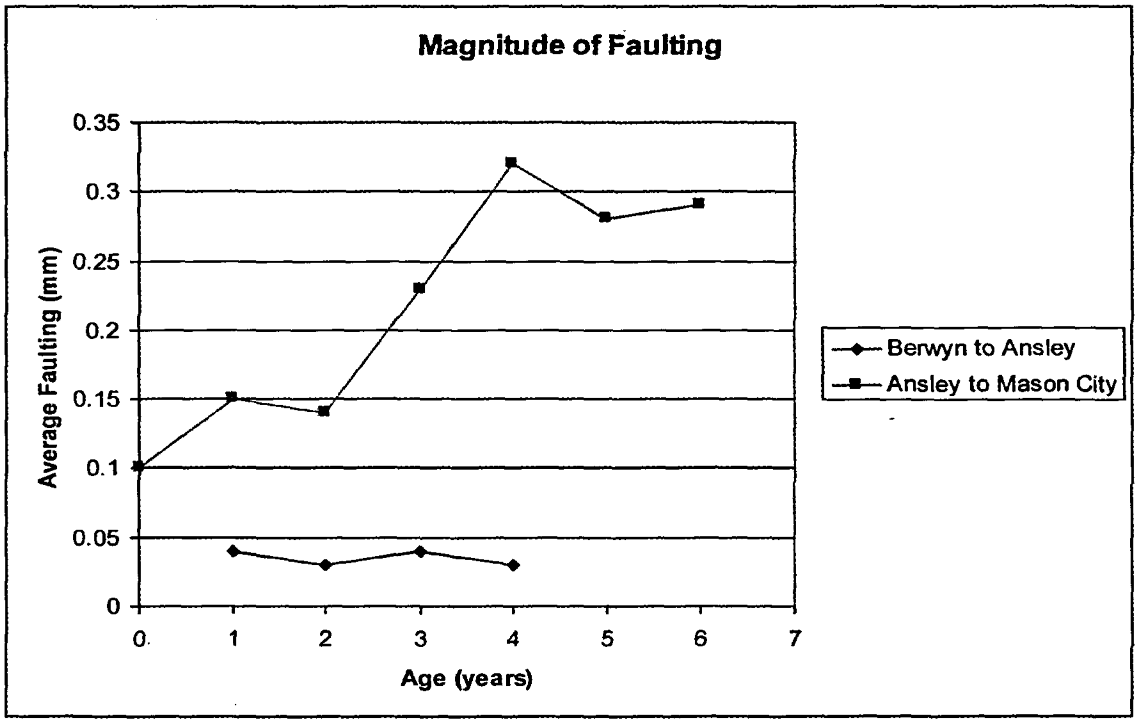

Figure 14. Faulting magnitude for concrete overlay on asphalt compared to conventional PCC pavement

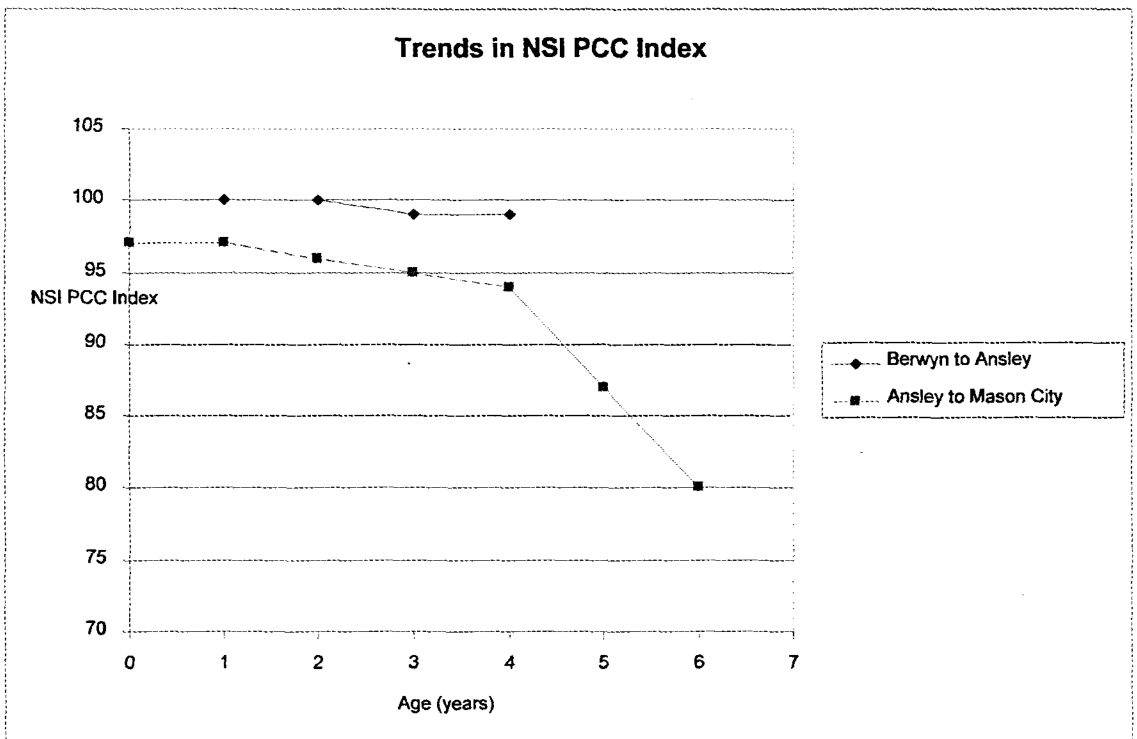

Figure 15. NSI PCC index for concrete overlay on asphalt compared to conventional non-doweled PCC pavement

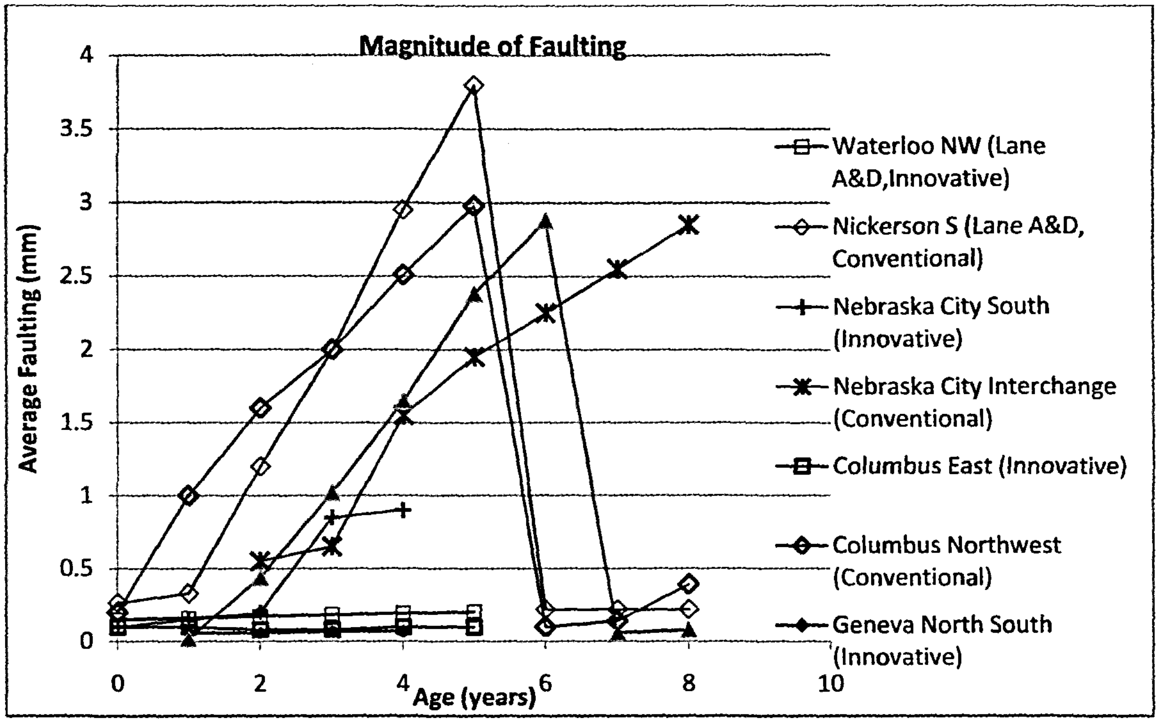

Figure 16. Compilation of faulting data for pavements with and without dowel bars

The dowelled concrete overlay on asphalt (Berwyn to Ansley) has outperformed the conventional PCC section (Ansley to Mason City) with regard to faulting, maintaining an average of less than 0.05 mm over its first four years of life. The conventional non-dowelled PCC pavement has shown an increased trend of faulting, especially during years two and three, with the magnitude increasing at an average rate of approximately 0.5 mm per year.

Figure 15—NSI PCC index for concrete overlay on asphalt compared to conventional non-doweled PCC pavement.

The doweled PCC overlay on asphalt has outperformed the non-doweled conventional section in relation to surface condition of the pavement. The PCC overlay has maintained a PCC NSI near 100, while the conventional pavement exhibited a decreasing trend

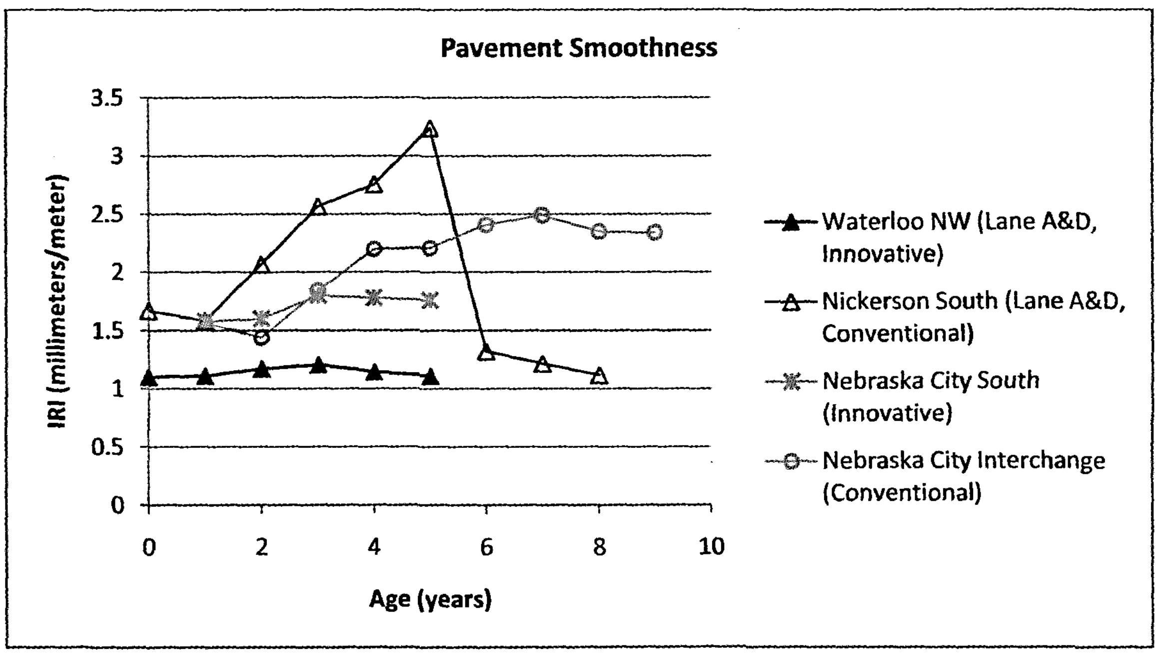

Figure 17. Effect of dowel bars (or the absence thereof) on pavement smoothness

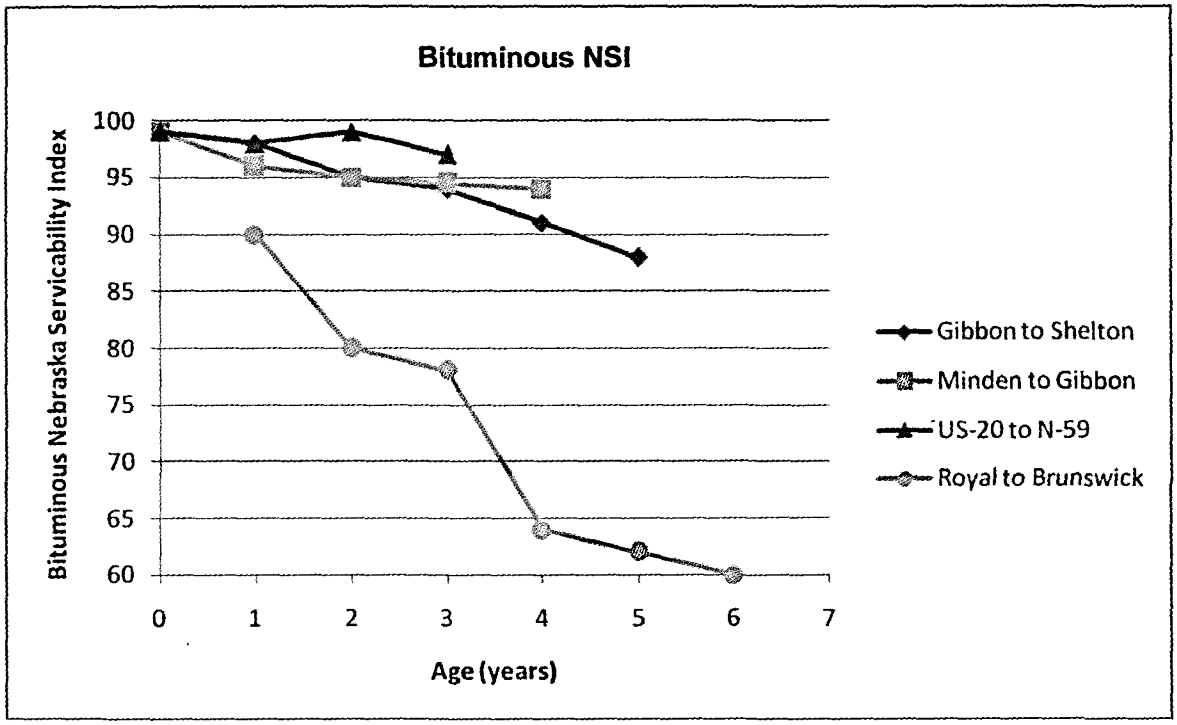

Figure 18. Bituminous NSI for crumb rubber modified versus two types of Superpave asphalt

in NSI after four years of life. The conventional pavement section is currently decreasing its NSI PCC index at the rate of approximately 5 points/year.

Figure 16 shows the combined plots for eight pavement sections where faulting was evaluated with and without dowel bars. Doweled PCC sections have steadily outperformed the non-doweled PCC on all subgrades, maintaining average faulting at less than 1.0 mm for all traffic loads and for all environmental conditions. The dowel bar retrofit successfully increased the performance of conventional sections to the point where they were nearly indistinguishable from dowelled new construction.

Figure 16—Compilation of faulting data for pavements with and without dowel bars (previous page).

Pavement smoothness remains better with the addition of dowel bars as well. ***Figure 17*** illustrates the effect of dowel bars on pavement smoothness for three pavement sections under varying traffic load and environmental conditions.

Figure 17—Effect of dowel bars (or the absence thereof) on pavement smoothness (previous page).

There was no quantifiable difference noted between crumb rubber modified asphalt and Superpave 4 asphalt pavement on the interstate highway sections. Both are showing similar distress resulting from the heavy volume of traffic that crosses Nebraska using Interstate 80. There were indications that the NSI bituminous index may be decreasing more rapidly for the crumb rubber modified asphalt during the past year.

Crumb rubber modified asphalt has outperformed Superpave 2 asphalt for rut depth (***Figure 12***) and NSI bituminous index for low volume roads. Crumb rubber modified asphalt has definitely outperformed Superpave 2 asphalt with regard to NSI bituminous index (***Figure 18***).

Figure 18—Bituminous NSI for crumb rubber modified versus two types of Superpave asphalt (previous page).

The doweled PCC overlay of milled asphalt has out-performed conventional non-doweled concrete pavement with regard to faulting and NSI PCC index over the first four years of life. These trends are expected to continue throughout the lifetime of both pavements.

CONCLUSIONS

The innovative features appear to be working well with regard to improving the performance level of pavements. Dowel bars, either placed during initial construction or retrofitted later, are proving effective in reducing faulting and maintaining higher NSI PCC indices. Crumb rubber asphalt performed in an effective manner initially under high volume traffic situations, and appears to perform exceptionally well in lower traffic volume situations with regard to rutting and bituminous NSI. A doweled PCC overlay placed over a milled asphalt base is outperforming non-doweled PCC pavement placed over a conventional subgrade.

Pavements with innovative features incorporated generally cost slightly to moderately more than conventional pavement sections. However, as shown by Figures 2 through 18, pavements with innovative features can often be retained in service for an extended period of time compared to their conventional counterparts. Longer service life of the innovative sections will significantly lower the annual cost of providing and maintaining quality pavement for vehicular traffic.

FUTURE STUDIES

Five pavement sections were added to the database during the current year including Plattsmouth West, Louisville East, Republican City–Naponee, Alma–Republican City and Malmo Spur West. Plattsmouth West and Louisville East have high Recycle Asphalt Pavement (RAP) bases with Superpave 4 wearing courses. Republican City–Naponee has ten centimeters of SP4 pavement over a fly ash stabilized subbase or twenty-five centimeters of SP4 asphalt over a subgrade which has been mixed, scarified, moisture content adjusted, shaped and compacted. Alma–Republican City has seventeen and one-half centimeters of asphalt over ten centimeters of foundation course. Malmo Spur West has six centimeters of asphalt over ten centimeters of hydrated lime slurry stabilized base.

Since these projects were release to for bid late in late 2006, or early 2007, physical parameters will be collected for the first time during the summer of 2008. These projects will be included in the next annual analysis of this study.

ACKNOWLEDGEMENTS

The authors would like to thank the Nebraska Department of Roads Materials and Research Division for funding this project for a five year period under research proposal SPR-1 P 563. Dave Medinger from the NDOR cheerfully provided information concerning various performance indicators from several databases. Moe Jamshidi, Amy Starr, Mick Syslo, Lieska Halsey, Jodi Gibson, and many other NDOR employees provided encouraging comments and helpful information throughout the course of this study. This report is the culmination of the efforts of three University Nebraska Construction Management students, Brad Rogge, Mike Barnard and Cody Kluver who have worked on this project over the five year period.

REFERENCES

Federal Highway Administration (2003). *Distress Identification Manual for the Long-Term Pavement Performance Program* (Report No.FHWA-RD-03-031). 6300 Georgetown Pike, McLean VA 22101: John S. Miller and William Y. Bellinger. Office of Infrastructure Research and Development <http://www.tfhrc.gov/pavement/ltpp/reports/03031>

Kluver, C. & Jensen, W. (2008). *Pavement Quality Indicators Study: Five Year Report* (SPR–1 P563). Nebraska Department of Roads, Materials and Research Division, 1400 Highway 2, Lincoln, Nebraska 68509

Nebraska Department of Roads (2002). *Pavement Maintenance Manual.* 1400 Highway 2, Lincoln, Nebraska 68509: Materials and Research Division

Nebraska Department of Roads (2008). *Appendix A to Pavement Management Systems.* 1400 Highway 2, Lincoln, NE 68509: Materials and Research Division. Retrieved July 2, 2008, from <http://www.dor.state.ne.us/mat-n-tests/pdfs-docs/npms.pdf>