Mn/ROAD PAVEMENT CONDITION
1994 - 1998
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The Minnesota Department of Transportation along with other partners, constructed forty 500-foot test sections from 1992 to 1994. The site, known as Mn/ROAD, is located along I-94, 40 miles northwest of the Twin Cities. Since the test sections are located at the same site, they are all subject to the same environmental conditions and traffic load. This makes direct comparisons of the pavement condition of the various cells possible. To accomplish this task, this paper will rely primarily on the use of computer graphics, due to the volume of the data collected and the number of test sections involved, to illustrate the changes in pavement condition that have occurred. Corresponding observations will be very general in nature and should be considered preliminary at this stage. More detailed analyses will be done on a cell by cell basis after all testing and final forensics have been completed. This paper will include a history of rutting, thermal cracking, fatigue cracking, ride, faulting, friction numbers, and construction costs.

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Mn/ROAD PAVEMENT CONDITION

1994 - 1998

Final Report

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The purpose of this paper is to provide an overview of the performance of the initial forty test sections at MnROAD over the first four and half years of the project.

CHAPTER 1 - INTRODUCTION

1.1 SCOPE
The Minnesota Department of Transportation along with other partners, constructed forty 500-foot test sections from 1992 to 1994. The site, known as MnROAD, is located along I-94, 40 miles northwest of the Twin Cities. Since the test sections are located at the same site, they are all subject to the same environmental conditions and traffic load. This makes direct comparisons of the pavement condition of the various cells possible. To accomplish this task, this paper will rely primarily on the use of computer graphics, due to the volume of the data collected and the number of test sections involved, to illustrate the changes in pavement condition that have occurred. Corresponding observations will be very general in nature and should be considered preliminary at this stage. More detailed analyses will be done on a cell by cell basis after all testing and final forensics have been completed. This paper will include a history of rutting, thermal cracking, fatigue cracking, ride, faulting, friction numbers, and construction costs.

1.2 TEST SECTIONS
MnROAD's test sections are referred to as cells. This paper will address only the original 22 asphalt concrete and 14 concrete cells opened to traffic in the summer of 1994; it will not include the 4 aggregate cells on the low volume road, the new whitetopping cells or the Superpave cells constructed in the fall of 1997. The locations of the cells and corresponding cell profiles are shown in Figure 1.1 (Low Volume Road) and Figure 1.2 (Mainline).

CHAPTER 2 - TRAFFIC

2.1 LOW VOLUME ROAD
Traffic began on the LVR on June 15, 1994. The traffic load is applied by a 5-axle tractor-trailer. On Wednesdays, the truck is loaded to 102,000 lbs. and driven around the loop on the outside lane in a counterclockwise direction. On the remaining four days of the week, the truck is loaded to 80,000 lbs. and driven in the opposite direction around the inside lane. The 80k lane therefore receives roughly four times (3.3 actually) the number of cycles as the 102k lane. Through October 27, 1998, 10,512 cycles had been completed on the 102k lane and 35,235 cycles on the 80k lane (Figure 2.1). The rate of application has been relatively steady over this time period with the exception of a three-month period from October through December 1997 when the project was without a driver. The average number of flexible ESALs through October 27, 1998 were 82,314 for the 80k lane and 75,027 for the 102k lane. And the average number of rigid ESALs were 131,636 for the 80k lane and 122,313 for the 102k lane. Total ESALs for all the cells on the LVR are shown in Figure 2.2.
2.2 MAINLINE
Traffic began on the mainline test sections on July 15, 1994. The mainline runs parallel to I-94 and uses the existing interstate traffic. Periodically the traffic is switched off the mainline back to the old roadway to allow researchers to safely collect data. The mainline traffic is monitored by a weigh in motion scale (WIM) located a half mile prior to the first test section, Cell 23. The WIM provides vehicle classification, speed, axle spacing, vehicle length, and axle weights by wheel path. ESALs through the end of October 1998 for the mainline are shown in Figure 5.

The WIM data to date is currently being reexamined. There have been numerous problems with the WIM scales and software. We are working on recovering the data.
TRAFFIC - LOW VOLUME ROAD
CYCLES THROUGH OCTOBER 27, 1998

TIME


Cycles

40000
35000
30000
25000
20000
15000
10000
5000
0

80k LANE
102k LANE

35,235
10,512

Figure 2.1
TRAFFIC - LOW VOLUME ROAD
ESALs THROUGH OCTOBER 27, 1998

<table>
<thead>
<tr>
<th>AC CELLS</th>
<th>CONCRETE CELLS</th>
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<tr>
<td>80k LANE</td>
<td>82,314</td>
</tr>
<tr>
<td>102k LANE</td>
<td>75,027</td>
</tr>
<tr>
<td></td>
<td>131,636</td>
</tr>
<tr>
<td></td>
<td>122,313</td>
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</table>

Figure 2.2
CHAPTER 3 - RUTTING

3.1 DATA COLLECTION
Rut depths have been recorded using a variety of methods. 1). The primary method used is a 6-foot straightedge. Maximum rut depths in each wheel path are measured by inserting drill bits between the surface of the pavement and the bottom of the straightedge. Two stations per cell are recorded for each recording date. Straightedge measurements are taken 3 to 4 times a year. In addition, in the summer of 1998, straightedge measurements were taken every 50 feet to study the variability of the rut depths across the length of the entire cell.

2). To record the transverse profiles, we initially used the Face Industries Dipstick. This tool measures the elevations at one foot intervals across the 24 foot pavement width. In the summer of 1998, we replaced the dipstick with a MnROAD version of an Arizona profiler. This device provides continuous to scale traces of the transverse profiles on 6-inch graph paper.

3). And finally we also record rut depths with MnDOT’s pavement management vehicles. Ultrasonic sensors (now laser beam) are mounted over the lwp, center and rwp and measure differences in elevation between the three points. These three points are averaged every 3 inches to compute rut depths along with a variety of other data including ride.

However, for this paper, all rut depths shown were recorded with the 6-foot straightedge. Figures 3.1 to 3.8 consist of stacked bar graphs that show the accumulation of rut depth over time. The five time segments were selected to correspond with the end of each of the five summer seasons. Each graph displays a different wheel path. The rut depths shown are the mean values of the two stations recorded for each cell.

Data for rutting is located in the RUTTING_STRAIGHT_EDGE table in the MnROAD database.

3.2 RUTTING - MAINLINE
- Significant rutting occurred soon after traffic began on July 15, 1994. Within four months, all the mainline cells had some rutting while in particular the rutting in cell 23 (0.25”) and cell 4 (0.18”) provided an early indication of rutting concerns in these two cells.
- Rutting continued to develop substantially over the second summer. By September 1995, most of the mainline cells had developed greater than 60 percent of their total accumulative rut depth to date, in the first 15 months of traffic. Cell 23 (0.43”), Cell 20 (0.38”), Cell 4 (0.32”), and Cell 2 (0.25”) had the deepest ruts. Figures 3.9 and 3.10 show the percentage of rut depth to date, which illustrates the extent of the rutting that occurred during the first two summers.
- The further development of rutting slowed down over the next three summers. The exceptions to this observation are cells 20 and 21, which continued to show greater increases in rut depth than the other cells.
- Through the first four and half years of the project, the stiffer AC 20 cells, (15, 16, 17, 18, 19) have resisted the development of rutting compared to the softer AC 120/150 cells.
- The right lane, as would be expected, has developed greater rut depths than the left lane.

3.3 SUMMER AIR TEMPERATURES
- Examination of the summer air temperatures (Figures 3.11 to 3.15) show the warmest summers were 1994 and 95, when the rutting was the greatest, with high temperatures exceeding 35 deg C. Air temperatures were lower in the summers of 96, 97, and 98, when the rutting was not as prevalent.

3.4 RUTTING - LOW VOLUME ROAD
- The development of rutting on the low volume road has been more uniform over time than the mainline.
- Rutting is greater in the 80k lane than the 102k lane. While receiving roughly the same number of ESALs, the 80k lane receives 3.3 times more cycles than the 102k lane. The deeper ruts in the 80k lane indicates that the number of cycles has had a greater effect on rutting than the number of ESALs.
- The greatest amount of rutting has occurred in cells 27 (0.8") and 28 (1.3"), both 3" thick HMAC.
- Cells 24 and 25, constructed on an R-70 sand subgrade have resisted the development of rutting compared to the other cells that were built on the R-12 clay subgrade.
- Rutting in the rwp is greater than the lwp for both the 80k and 102k lanes.
Figure 3.1
RUT DEPTHS - MnROAD MAINLINE

RIGHT LANE - LWP

RUT DEPTH (inches)

CELL NUMBER

Fig. 3.2
RUT DEPTHS - MnROAD MAINLINE

LEFT LANE - RWP

RUT DEPTH (inches)

CELL NUMBER

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

0 5 10 15

Nov-98
Sep-97
Oct-96
Sep-95
Nov-94

Figure 3.3
RUT DEPTHS - MnROAD MAINLINE

LEFT LANE - LWP

RUT DEPTH (inches)

CELL NUMBER

Figure 3.4
Figure 3.5

RUT DEPTHS - MnROAD LVR

80k LANE - RWP

CELL NUMBER

RUT DEPTH (inches)

Nov-98
Sep-97
Aug-96
Sep-95
Nov-94

(mm)

25
20
15
10
5
0
RUT DEPTHS - MnROAD LVR

102k LANE - RWP

RUT DEPTH (inches)

CELL NUMBER

Figure 3.7
RUT DEPTHS - MnROAD LVR

102k LANE - LWP

RUT DEPTH (inches)

25
20
15
10
5
0

CELL NUMBER

Figure 3.8
Figure 3.9
MnROAD AIR TEMPERATURES SUMMER 1995

TEMPERATURE (°C)

MAY  JUN  JUL  AUG  SEP  OCT

Figure 3.12
MnROAD AIR TEMPERATURES SUMMER 1996

- Maximum
- Minimum

TEMPERATURE (°C)

MAY  JUN  JUL  AUG  SEP  OCT

Figure 3.13
MnROAD AIR TEMPERATURES SUMMER 1998

Temperature (°C)

MAY  JUN  JUL  AUG  SEP  OCT

Figure 3.15
CHAPTER 4 - THERMAL CRACKING

4.1 DATA COLLECTION - Formal distress surveys are conducted twice a year. These occur after the spring thaw and in the fall, prior to the first hard freeze. All cracks are mapped and rated according to the methods described in the SHRP LTPP Distress Identification Manual.

4.2 WINTER AIR TEMPERATURES
Winter air temperatures are shown in Figures 4.1 to 4.4. Almost all of the thermal cracking at Mn/ROAD occurred between February, 1996 and the end of April, 1996. This cracking coincided with the coldest winter of the last century in Minnesota. Air temperatures at Mn/ROAD reached minus 42 deg F and AC surface temperatures reached minus 23 deg. F (Figures 4.5 and 4.6). Not only was this winter associated with bitter cold temperatures but it also produced multiple severe temperature swings throughout the whole winter season (Figure 4.2). Prior to the 1995/96 winter, a small amount of thermal cracking occurred in the AC 20 mainline cells (16, 17, 18, and 19) in January of 1994. During the other three winters, the amount of thermal cracking remained virtually unchanged. The total lineal feet of thermal cracking for the five winters to date is shown in Figure 4.7 (mainline) and Figure 4.8 (LVR). To date, very few cracks have reached the moderate severity level.

Data for all types of AC cracking is located in the DISTRESS_AC_CRACKS table in the MnROAD database.

4.3 THERMAL CRACKING - MAINLINE
- The AC 20 cells (15, 16, 17, 18, 19 and 20) have cracked substantially more than the AC 120/150 cells (Figures 4.7 and 4.8).
- The AC 20 cells (16, 17, 18, 19, and 20) were the only cells to crack initially in January, 1994. While there was only 15 total cracks during this first event, some of these cracks were substantial, opening to a width of 0.25 inches and running transversely through the shoulders and several feet into the subgrade beyond. By examining subsequent crack maps, it is evident that these early cracks provided stress relief in the local vicinity, preventing cracks that would have developed around them during the second cold winter in 1996. This observation seems to validate the concept of the saw and seal construction methods used to reduce the incidence of thermal cracking (Figures 4.9 and 4.10).
- The AC 20 cells, in addition to being more extensive, also exhibited a different fracture pattern than the AC 120/150 cells. The AC 120/150 cells developed more typical straight transverse cracks spaced 40 to 60 feet apart. By comparison, the AC 20 cells fractured in a more random jagged pattern with many short cracks (Figures 4.9 and 4.10).
- More thermal cracks have developed in the right lane than the left lane. This suggests that the traffic load has some influence in the development of these cracks (Figure 4.11).
4.3 THERMAL CRACKING – LOW VOLUME ROAD

- The 3" HMA cells 24, 27, and 28 have developed more thermal cracks than the thicker cells. The exception is 3” cell 31, which has very minor cracking (Figure 4.8).
- The thickest section, Cell 26 (6” full depth on clay) has almost no thermal cracks.
- Cell 24 and Cell 27 constructed on a class 6 base have experienced the greatest amount of thermal cracking.
- There is little difference in the amount of thermal cracking between the 80k lane and the 102k lane (Figure 4.12).
MnROAD AIR TEMPERATURES WINTER 94/95

TEMPERATURE (°C)

Figure 4.1
MnROAD AIR TEMPERATURES WINTER 95/96

TEMPERATURE (°C)

-40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20

NOV DEC JAN FEB MAR APR

- Maximum
- Minimum

Figure 4.2
MnROAD AIR TEMPERATURES WINTER 96/97

TEMPERATURE (°C)

Maximum
Minimum

NOV  DEC  JAN  FEB  MAR  APR

Figure 4.3
THERMAL CRACKS - MAINLINE

Figure 4.7

AMBIENT AIR TEMP ON FEBRUARY 2, 1996 = minus 42 deg F.

LINEAL FT OF CRACKS

AC 20 CELLS

AC 120/150 CELLS

CELL 1

CELL 2

CELL 3

CELL 4

CELL 14

CELL 15

CELL 16

CELL 17

CELL 18

CELL 19

CELL 20

CELL 21

CELL 22

CELL 23

TIME

93-94

94-95

95-96

96-97

97-98
THERMAL CRACKS - LVR

Figure 4.8
THERMAL CRACKS - MAINLINE
THROUGH OCTOBER, 1998

Figure 4.11
THERMAL CRACKS - LVR
THROUGH OCTOBER, 1998

Figure 4.12
CHAPTER 5 - FATIGUE CRACKING

5.1 DATA COLLECTION
Fatigue cracking was first spotted in the 80k lane of cell 28 in the spring of 1997. Subsequent forensics on cell 28 have determined that these cracks were actually surface initiated rather than true fatigue. An examination of the ground penetrating radar pavement thickness plot for the cell showed that the initial 40 feet of fatigue developed in the thinnest section of the cell. (2.3” as built for a 3” design- Figure 36) By the middle of November, 1997, the amount of fatigue in cell 28 had reached 200 lineal feet of low to moderate severity in the 80k lane and 50 feet in the 102k lane. Fatigue was also spotted on the mainline in the AC 20 cells 18 and 19. The fatigue in these mainline cells first began as small longitudinal cracks emanating perpendicular to the transverse thermal cracks. Over time these cracks continued to expand in the wheel paths in either direction away from the thermal cracks. By the spring of 1998, fatigue was found in cells 27, 28 and 31 on the LVR and in cells 2, 4, 15, 18, 19 and 23 on the mainline. At this point, cell 28 had 470 lineal feet of the 1,072 total lineal feet of fatigue for all the cells combined. By October, 1998, the amount of fatigue increased to 3,167 total feet. With the exception of portions of cell 28, all of this fatigue is rated low level severity. Typically these are short, less than 6” longitudinal cracks spaced one to three feet apart in the wheel paths. Without moisture in these hairline cracks, they can be difficult to see. The amount of fatigue to date is shown in Figures 5.1 and 5.2.

Data for all types of cracking is located in the DISTRESS_AC_CRACKS table in the MnROAD database.

5.2 FATIGUE CRACKING - MAINLINE
- Through October, 1998, seven cells, 1, 14, 16, 17, 20, 21, and 22 have no fatigue.
- Three cells, 3, 15 and 23 have very minor fatigue.
- The remaining four cells, 2, 4, 18, 19 have substantial fatigue.
- On the mainline, there is a surprising amount of fatigue in the left lane compared to the right lane (Figure 5.3). Cells 4, 15, 18 and 23 actually have more fatigue in the left lane (passing lane) than the right lane (driving lane).

5.3 FATIGUE CRACKING - LOW VOLUME ROAD
- Five cells, 24, 25, 26, 29, and 30 have no fatigue.
- Cell 31 has a very small amount of fatigue, 35 lineal feet.
- Cells 27 and 28 have substantial fatigue, 210 and 710 lineal feet respectively.
- The 80k lane has developed more fatigue than the 102k lane (Figure 5.4).
FATIGUE CRACKING - MAINLINE

LEFT LANE

RIGHT LANE

CELL NUMBER

Figure 5.2
FATIGUE CRACKING - LVR

102k LANE

80k LANE

<table>
<thead>
<tr>
<th>CELL NUMBER</th>
<th>10/2/98</th>
<th>4/29/98</th>
<th>11/15/97</th>
<th>4/30/97</th>
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<tr>
<td>27</td>
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<th>CELL NUMBER</th>
<th>27</th>
<th>28</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>80k LANE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 6 - FAULTING

6.1 DATA COLLECTION
Faulting is measured using a Georgia faultmeter. Readings are taken on every joint at two distances, 1 foot and 2.5 feet, from the panel shoulder edge. Readings are taken once a year, although the frequency will be increased to three times a year starting in 1999. This method is described in the SHRP LTTP Distress Manual. Faulting is depicted in Figures 6.1-6.4. Pumping observations are recorded in field notes. Pumping was first observed on the LVR in the fall of 1994 and the summer of 1995 in cells 39 and 40. A minor amount of pumping was observed in cell 11 on the mainline in the summer of 1995.

The data for faulting is located in the GEORGIAFAULTMETER_PCC_DATA table in the MnROAD database.

6.2 FAULTING - MAINLINE
- There has been very little faulting on any of the MnROAD cells.
- There are very few joints on the mainline that exceed a fault depth of 1 mm. One joint in the transition zone between cells 6 and 7 has reached 5 mm. This joint unlike the other skewed joints is a perpendicular construction joint placed at the end of the paving day.

6.3 FAULTING - LOW VOLUME ROAD
- On the LVR, only cell 40 has fault readings consistently greater than 1 mm. These range from 1 to 4 mm. While this level of faulting is greater than that found on the other concrete cells at MnROAD, it is still very minor and only has a slight impact on ride. Cell 40 has no dowels and was constructed on 5 inches of class 5 base over a clay subgrade. This cell was observed to have the greatest amount of pumping.
- The other LVR concrete cell constructed without dowels, cell 37, has slightly greater faults (just slightly exceeding 1 mm) than the adjacent cells in the 80k lane. Cell 37 was constructed on 12” of class 5 over a sand subgrade.
- The 80k lane with 3.3 times the number of cycles has slightly more faulting than the 102k lane. Both lanes have received roughly the same number of ESALs.
CHAPTER 7 - ROUGHNESS

7.1 DATA COLLECTION

Ride has been measured with two different vehicles. From the beginning through June 27, 1997, a van equipped with PaveTech equipment was used. In July of 1997, Mn/DOT’s Pavement Management Office switched to Pathways equipment. One major difference between the two systems is that the PaveTech vehicle used ultrasonics to measure the variation in longitudinal profile while the Pathways vehicle uses laser beams. The unit of measurement is the International Roughness Index, IRI, in m/km. Because the texture of the surface of the pavement tends to scatter the ultrasonic sound waves, the IRIs recorded by the Pathways vehicle are higher than the IRIs recorded by the Pathway’s laser beam. Equations have been developed to convert from one format to the other. For the purpose of this paper, all IRIs are reported in the Pathways format. Figures 7.1 (mainline) and 7.2 (LVR) show the deterioration in ride over time for each of the cells. These bar graphs show the difference from the initial IRI in 1994 to the latest IRI recorded on November 11, 1998.

Data for ride is located in the PATHWAYS_VALUES table in the MnROAD database.

7.2 ROUGHNESS MAINLINE

The HMA cells have shown a much greater increase in IRI than the concrete cells through the first four and half years. These increases range from 0.1 to 1.1 m/km for the HMA cells with a typical average increase of about 0.4 m/km. In contrast, the increases in IRI for the concrete cells show almost no change in IRI. The exception is cell 6, which has shown an increase of 0.6 m/km in the right lane. This increase in the right lane may be due to the roughness introduced by a striping study that was placed in the transition zones between adjacent cells 5 and 7. There is no increase in the amount of faulting in cell 6 to otherwise explain the increase in IRI for that cell.

- Amongst the HMA cells, the AC 20 cells (15, 16, 17, 18, and 19) have shown a greater increase in IRI than the AC 120/150 cells.
- Also on the mainline, the right lane has shown greater increases in IRI than the left lane.

7.3 ROUGHNESS LOW VOLUME ROAD

- On the LVR, the 3 inch thick HMA cells 27 and 28 have shown the greatest increases in IRI ranging from 0.6 to 0.8 m/km.
- Also on the LVR, the concrete cells have shown a greater increase in the IRI (0.2 to 0.4 m/km) than the concrete cells on the mainline which showed almost no change.
- HMA cells 24, 25, 26, 29, 30, and 31 have shown surprisingly little increases in IRI.
- It should be noted that the roughness in cell 36 in 1998 was affected by aggregate dragged on to the cell from adjacent aggregate cell 35 and the roughness in the 102k lane of cell 26 is exaggerated due to the development of a couple of persistent pot holes.

Figures 7.3 to 7.52 show plots of IRI versus time for each cell. The data points are the mean values of the multiple runs recorded for each season, summer and winter. Previous studies at MnROAD have shown an increase in roughness during the winter season due to the effects of frost heave and the tenting of thermal cracks. These winter effects on ride dissipate during the summer (Figure 7.53 and 7.54). For this reason, both summer and winter roughness measurements are included in this analysis. Also included on each graph is a least squares linear regression plot to show the trend line over time.
CHANGE in IRI from 1994 to 1998

Figure 7.1
CHANGE in IRI from 1994 to 1998

- **102k LANE**
- **80k LANE**

Cell 26 1998 roughness due to development of several potholes in 102k lane.

Cell 36 1998 roughness due to aggregate dragged from adjacent aggregate cell 35.

Figure 7.2
INTERNATIONAL ROUGHNESS INDEX

MAINLINE - RIGHT LANE

CELL 1

\[ y = 0.067x + 0.4607 \]

\[ R^2 = 0.7049 \]

Figure 7.3
INTERNATIONAL ROUGHNESS INDEX

MAINLINE - RIGHT LANE

CELL 2

\[ y = 0.0865x + 0.4755 \]

\[ R^2 = 0.5547 \]

Figure 7.4
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 3

\[ y = 0.0645x + 0.6788 \]
\[ R^2 = 0.6857 \]
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 4

\[ y = 0.0884x + 0.7453 \]

\[ R^2 = 0.582 \]

Figure 7.6
INTERNATIONAL ROUGHNESS INDEX

MAINLINE - RIGHT LANE

CELL 5

\[ y = 0.0178x + 0.9622 \]

\[ R^2 = 0.1945 \]

Figure 7.7
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

Figure 7.8

CELL 6

\[ y = 0.0461x + 0.9498 \]

\[ R^2 = 0.4034 \]
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 7

$y = 0.0021x + 0.8475$
$R^2 = 0.0012$

Figure 7.9
INTERNATIONAL ROUGHNESS INDEX

MAINLINE - RIGHT LANE

CELL 8

\[ y = 0.0041x + 1.3336 \]

\[ R^2 = 0.0634 \]

Figure 7.10
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 9

\[ y = 0.0192x + 0.8487 \]

\[ R^2 = 0.4915 \]
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 10

\[ y = 0.0006x + 0.9728 \]

\[ R^2 = 0.0006 \]

Figure 7.12
Figure 7.13

Time
86 S 88 W 90 S 92 W 94 S 96 W 97 S 95 W 94 S 96 W 97 S 95 W 94 S 96 W 97 S 95 W 94 S

IRI (m/km)
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

Cell 11

Mainline - Right Lane
International Roughness Index

$R^2 = 0.2183$

$y = -0.014x + 1.1785$
$R^2 = 0.3903$

$y = 0.0139x + 0.887$

Figure 7.4

**TIME**

86 S 86 W 77 S 77 W 96 S 96 W 95 S 95 W 94 S

**IRI (m/km)**

8.0 9.0 10.0 11.0 12.0

**CELL 12**

**MAINLINE - RIGHT LANE**

**INTERNATIONAL ROUGHNESS INDEX**
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 13

\[ y = 0.0286x + 0.7157 \]
\[ R^2 = 0.5923 \]

Figure 7.15
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 14

y = 0.0608x + 0.5106
$R^2 = 0.421$

Figure 7.16
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 15

\[ y = 0.0739x + 0.4398 \]

\[ R^2 = 0.5223 \]
INTERNATIONAL ROUGHNESS INDEX

MAINLINE - RIGHT LANE

CELL 16

\[ y = 0.1026x + 0.3415 \]

\[ R^2 = 0.7405 \]

Figure 7.18
INTERNATIONAL ROUGHNESS INDEX

MAINLINE - RIGHT LANE

CELL 17

\[ y = 0.0641x + 0.55 \]

\[ R^2 = 0.668 \]

Figure 7.19
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 18

\[ y = 0.1384x + 0.3001 \]
\[ R^2 = 0.7648 \]

Figure 7.20
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 19

\[
y = 0.0924x + 0.4153
\]

\[
R^2 = 0.6481
\]

Figure 7.21
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 20

\[ y = 0.0392x + 0.444 \]

\[ R^2 = 0.3156 \]
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 21

\[ y = 0.0408x + 0.4372 \]
\[ R^2 = 0.569 \]

Figure 7.23
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 22

\[ y = 0.0754x + 0.401 \]
\[ R^2 = 0.6342 \]

Figure 7.24
INTERNATIONAL ROUGHNESS INDEX
MAINLINE - RIGHT LANE

CELL 23

\[
y = 0.0937x + 0.5414
\]

\[
R^2 = 0.7172
\]
INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 102k LANE

CELL 24

\[ y = 0.0286x + 0.6938 \]

\[ R^2 = 0.3641 \]

Figure 7.26
INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 102k LANE

CELL 25

\[ y = 0.0143x + 0.6205 \]
\[ R^2 = 0.2924 \]

Figure 7.27
Figure 7.28

INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 102k LANE

CELL 26

y = 0.0678x + 0.829

R² = 0.5017
INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 102k LANE

CELL 28

\[ y = 0.0579x + 0.534 \]
\[ R^2 = 0.8222 \]

Figure 7.30
INTERNATIONAL ROUGHNESS INDEX

LOW VOLUME ROAD - 102k LANE

CELL 29

\[ y = 0.0255x + 0.6149 \]

\[ R^2 = 0.6668 \]

Figure 7.31
Figure 7.32

TIME

S 94 W 95 S 96 W 96 S 97 W 97 S 98 W 98 S 98

IRI (m/km)

\[ R^2 = 0.2721 \]
\[ y = 0.0165x + 0.718 \]

CELL 30

LOW VOLUME ROAD - 102K LANE

INTERNATIONAL ROUGHNESS INDEX
INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 102k LANE

CELL 31

\[ y = 0.0061x + 1.1108 \]

\[ R^2 = 0.0057 \]

Figure 7.33
INTERNATIONAL ROUGHNESS INDEX

LOW VOLUME ROAD - 102k LANE

CELL 36

\[ y = 0.0139x + 0.804 \]
\[ R^2 = 0.6915 \]

Figure 7.34
INTERNATIONAL ROUGHNESS INDEX

LOW VOLUME ROAD - 102k LANE

CELL 37

\[ y = 0.0141x + 0.6646 \]
\[ R^2 = 0.7578 \]

Figure 7.35
INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 102k LANE

CELL 38

$y = 0.0128x + 0.979$

$R^2 = 0.0105$

Figure 7.36
INTERNATIONAL ROUGHNESS INDEX

LOW VOLUME ROAD - 102k LANE

CELL 39

\[ y = 0.0146x + 0.8179 \]
\[ R^2 = 0.2797 \]

Figure 7.37
INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 102k LANE

CELL 40

\[ y = 0.0661x + 1.0062 \]
\[ R^2 = 0.5551 \]

Figure 7.38
INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 80k LANE

CELL 24

\[ y = 0.0071x + 0.5269 \]
\[ R^2 = 0.1137 \]

TIME

Figure 7.39
INTERNATIONAL ROUGHNESS INDEX

LOW VOLUME ROAD - 80k LANE

Figure 7.40

CELL 25

\[ y = 0.0092x + 0.5221 \]

\[ R^2 = 0.2244 \]
INTERNATIONAL ROUGHNESS INDEX

LOW VOLUME ROAD - 80k LANE

CELL 26

\[ y = 0.0304x + 0.9789 \]

\[ R^2 = 0.2544 \]

Figure 7.41
P'Line 7.42

TIME

S '96 S '98 W '98 S '97 W '97 S '96 W '96 S '96 W '95 S '95 W '94 S '94

IRI (m/km)

1.0

0.8

0.6

0.4

0.2

0.0

CCELL 27

LOW VOLUME ROAD - 80K LANE

INTERNATIONAL ROUGHNESS INDEX

R^2 = 0.8821

Y = 0.0797x + 0.6319
INTERNATIONAL ROUGHNESS INDEX

LOW VOLUME ROAD - 80k LANE

CELL 28

\[ y = 0.0859x + 0.367 \]

\[ R^2 = 0.7828 \]

Figure 7.43
INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 80k LANE

CELL 29

\[ y = 0.0097x + 0.6214 \]
\[ R^2 = 0.3426 \]
INTERNATIONAL ROUGHNESS INDEX

LOW VOLUME ROAD - 80k LANE

CELL 30

\[ y = 0.0178x + 0.6386 \]

\[ R^2 = 0.2491 \]

Figure 7.45
INTERNATIONAL ROUGHNESS INDEX

LOW VOLUME ROAD - 80k LANE

CELL 31

\[ y = 0.0361x + 0.6802 \]

\[ R^2 = 0.3715 \]

Figure 7.46
INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 80k LANE

CELL 36

\[ y = 0.0648x + 0.679 \]

\[ R^2 = 0.3862 \]

Figure 7.47
INTERNATIONAL ROUGHNESS INDEX

LOW VOLUME ROAD - 80k LANE

CELL 37

\[ y = 0.0266x + 0.6488 \]

\[ R^2 = 0.6359 \]

Figure 7.48
Figure 7.49

INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 80k LANE

CELL 38

\[ y = 0.0281x + 1.0547 \]

\[ R^2 = 0.0436 \]
INTERNATIONAL ROUGHNESS INDEX

LOW VOLUME ROAD - 80k LANE

CELL 39

\[ y = 0.0251x + 0.9372 \]

\[ R^2 = 0.3987 \]

Figure 7.50
INTERNATIONAL ROUGHNESS INDEX
LOW VOLUME ROAD - 80k LANE

Figure 7.51
Change in IRI
AC cells 1-4, left lane

IRI change [m/km]

SU '94 WI '95 SU '95 WI '96 SU '96 WI '97 SU'97

1 2 3 4 AVE

Figure 7.52
PRESENT SERVICEABILITY RATING
MAINLINE - NOVEMBER 4, 1998

Figure 7.54
PRESENT SERVICEABILITY RATING
LVR - NOVEMBER 4, 1998

Figure 7.55
CHAPTER 8 - FRICTION

8.1 DATA COLLECTION
Friction data is collected using a K.J. Law, model 1290 tester. This is a dynamic locked wheel device that measures the skid resistance under wet conditions. These tests are conducted as specified by ASTM-E 274-90. Each lane of each cell is tested in one specified location. In each subsequent testing date, an effort is made to test the same exact location. Through the first four years, ten tests have been run. Typical results are shown in Figures 8.1 to 8.4, along with the least squares linear regressions to show the trend lines over time. The changes in friction numbers from 6/23/94 to 10/14/98 are shown in figures 8.5 to 8.8.

Friction data is located in the FRICTION_DATA table in the MnROAD database.

8.2 FRICTION MAINLINE
- On the mainline HMA cells, the initial friction numbers ranged from 53 to 60 prior to opening to traffic in June 1994. There was no difference between the right lane and the left lane and there was also no difference between the AC 20 cells and the AC 120/150 cells.
- Over the first four and half years, the friction numbers on the HMA cells have dropped an average of 10.7 in the left lane and an average of 15.8 in the right lane. Examination of the trend lines show that the most recent values, recorded in the fall of 1998, range from 45 to 48 for the left lane and from 41 to 43 for the right lane. The right lane has been worn smoother as would be expected.
- On the mainline concrete cells, the initial friction numbers ranged from 56 to 65. There was little difference between the right and left lanes. But the thicker 10-year cells (10, 11, 12, and 13) had slightly higher initial friction numbers in June, 1994, than the 5-year cells (5, 6, 7, 8, and 9). This may be due to the fact that the 5-year cells were constructed one year before the 10-year cells.
- The friction numbers on the 5-year concrete cells dropped an average of 7.6 in the left lane and an average of 15.7 in the right lane.
- The drop in the 10-year cells have been greater than the drop in the 5-year cells, averaging 9.6 in the left lane and 19.6 in the right lane.
- It should be noted that the paver broke down during the construction of cell 8, which required a subsequent milling of the surface. The initial friction numbers were lower for this cell and are currently lower than the other 5 year concrete cells.

8.3 FRICTION LOW VOLUME ROAD
MnROAD FRICTION NUMBERS

CELL 9

\[ y = -0.004x + 60.4 \quad R^2 = 0.30 \]

\[ y = -0.0058x + 57.8 \quad R^2 = 0.51 \]

Figure 8.1
MnROAD FRICTION NUMBERS

CELL 23

Friction Number (FN)


\[ y = -0.0023x + 51.1 \]
\[ R^2 = 0.15 \]

\[ y = -0.0041x + 48.4 \]
\[ R^2 = 0.27 \]
MnROAD FRICTION NUMBERS

CELL 28

FRICION NUMBER (FN)


Figure 8.3
FRICTION NUMBERS - LVR

102k LANE

Figure 8.8
- The initial friction numbers for the LVR HMA cells ranged generally from 55 to 65. Unlike the mainline, which showed a decline in the friction numbers, there has been little change in these numbers on the LVR. The latest readings are close to a value of 60, with little difference between the 80k and the 102k lanes.
- The initial friction numbers for the LVR concrete cells ranged from 62 to 67. These numbers have dropped an average 4.2 for the 80k lane and 5.2 for the 102k lane.

CHAPTER 9 - CONSTRUCTION COSTS
Table 9.1 shows the estimated construction costs for each cell and Figures 9.1 and 9.2 show a bar graph plot of these figures.

SUMMARY
This paper has shown a wide variation from one cell to another, in the amount of the various pavement distresses that have developed over the first four and half years at Mn/ROAD. It is anticipated that cells 27 and 28 will have failed by the end of this spring thaw, 1999. They will be replaced by new cells, along with the four aggregate cells, on the LVR. The future challenge for researchers will be to explain what has caused these differences in pavement condition and what long term effect do these results have on the future of pavement design.
COST PER MILE - MAINLINE

COST PER MILE ($1000)

AC    CONCRETE    AC

CELL NUMBER

Figure 9.2