Developing a Surface Drainage Rating for Inclusion in TxDOT’s Asset Management System: Presentation

Technical Report 0-6896-P1

Cooperative Research Program
DEVELOPING A SURFACE DRAINAGE RATING FOR INCLUSION IN TxDOT’S ASSET MANAGEMENT SYSTEM: PRESENTATION

by

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Developing a Surface Drainage Rating for Inclusion in TxDOT’s Asset Management System
TxDOT Project 0-6896

Project Close Out Meeting
November 21, 2017
Abstract

Develop a drainage rating system aided by the collection of data through automated means. Test this system on a range of TxDOT’s network to determine adequacy. Illustrate the use of drainage information at both the network and project levels.
Project Evolution

• Mobile LiDAR returns a measurement when it impacts a surface

• Roadway design balances safety and drainage with safety held paramount
  – Design standards are used as a baseline for rating
  – Design standards do not always benefit drainage

• A surface drainage project by its nature becomes a surface geometric project
  – Can include an evaluation of design compliance
Mobile LiDAR Systems

• Components
  – Vehicle: in-vehicle computer and software, laser, GPS, inertial measurement unit (IMU), accelerometer, camera, DMI
  – Desktop: post-processing software
TTI Mobile LiDAR Unit

• Hardware and software manufactured by Roadscanners Oy of Finland
Mobile LiDAR Data Collection Basics
Longitudinal Spacing

- Spacing between strings of data at approximately 8 inches at 45 mph
Transverse Spacing

- Transverse spacing on paved surface is typically less than 10 inch spacing.
- Spacing is less than 3 inches across the data collection lane.
- Adjacent to the data collection direction spacing between point is typically within 4-ft.
<table>
<thead>
<tr>
<th>No. Thru Lanes</th>
<th>Potential Roadway Type</th>
<th>Paved Width (ft)</th>
<th>Lane Configuration</th>
<th>Data Collection Lane</th>
<th>Distance between Transverse Measurements at Specific Locations (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>One roadway of a divided hwy</td>
<td>38</td>
<td>4′/12′/12′/10′ (Shld./2 Lanes/Shld.)</td>
<td>Outside Lane</td>
<td>7.75/3.70</td>
</tr>
<tr>
<td>4</td>
<td>Opposing traffic with no median or single direction multi-lane facility</td>
<td>56</td>
<td>4′/48′/4′ (Shld./4 Lanes/Shld.)</td>
<td>Outside Lane</td>
<td>25.37/18.08</td>
</tr>
<tr>
<td>4</td>
<td>Opposing traffic with no median; 4 lane single direction multi-lane facility</td>
<td>56</td>
<td>4′/48′/4′ (Shld./4 Lanes/Shld.)</td>
<td>Inside Lane</td>
<td>14.8</td>
</tr>
<tr>
<td>3</td>
<td>Super-2 or passing lane in a single direction; 3 lane single direction facility</td>
<td>50</td>
<td>10′/36′/4′ (Shld./3 Lanes/Shld.)</td>
<td>Outside Lane</td>
<td>21.26</td>
</tr>
<tr>
<td>3</td>
<td>Super-2 or passing lane in a single direction; 3 lane single direction facility</td>
<td>50</td>
<td>10′/36′/4′ (Shld./3 Lanes/Shld.)</td>
<td>Inside Lane</td>
<td>10.7</td>
</tr>
<tr>
<td>3</td>
<td>Super-2 or passing lane in a single direction; 3 lane single direction facility</td>
<td>50</td>
<td>10′/36′/4′ (Shld./3 Lanes/Shld.)</td>
<td>Single lane direction</td>
<td>14.8</td>
</tr>
<tr>
<td>5</td>
<td>5 lane single direction facility; two-way traffic with a flush median or turn lane.</td>
<td>74</td>
<td>4′/60′/10′ (Shld./5 Lanes/Shld.)</td>
<td>Middle Lane</td>
<td>18.59</td>
</tr>
<tr>
<td>5</td>
<td>5 lane single direction facility; two-way traffic with a flush median or turn lane.</td>
<td>74</td>
<td>4′/60′/10′ (Shld./5 Lanes/Shld.)</td>
<td>Outside Lane</td>
<td>54.36</td>
</tr>
<tr>
<td>5</td>
<td>Crowned two-way traffic with flush median or turn lane</td>
<td>82</td>
<td>10′/24′/14′/24′/10′ (Shld./2 Lanes/Turn Lane/2 Lanes/Shld)</td>
<td>Inside Lane</td>
<td>33.49</td>
</tr>
</tbody>
</table>
Conversion of Raw LiDAR Data to Gridded Data

- 1-ft x 1-ft gridded surface for paved area
- 3-ft x 3-ft gridded surface for roadside
Mobile LiDAR Accuracy within Study

• Individual components, such as the inner workings of the laser, are certified as accurate and precise by the manufacturer
• Focus of accuracy is on roadway elements
• Often requires some processing of the data
Mobile LiDAR Accuracy for Rated Elements

- Longitudinal length: within ±0.15% of actual length
  - ± 1.8 inches in every 100-ft
- Data collection lane cross slope: ± 0.05% and ±0.10%
- Adjacent lane cross slope: ± 0.20%
- Adjacent to data collection lane front slope steepness: ±0.5H:1V
  - Typically flatter
  - More variable on the opposite roadside
- Ditch offsets are measured within the 3-ft window of the grid
- Ditch depths are typically more shallow due to vegetation. Depth differences can typically be explained by vegetation height on roadside adjacent to data collection lane
- Rut depth in data collection lane: ±0.05 inches
Example of Accuracy Check

Grass causing elevation spike in Figure 14.
Network Level Elements

- Traveled way width
- Travel lane cross slope
- Hydroplaning potential
- Front slope steepness
- Ditch depth
- Ditch flowline steepness
Requires additional processing (manual)

- Curb height (if applicable)
- Outside lane ponding in C&G sections
- Edge condition
- Intersection radii
- Non-uniform cross section
- Inlet condition

Parallel and cross structures require manual inspection.
Network Level Elements: Lane Width

- Based on 3R and 4R design requirements

<table>
<thead>
<tr>
<th>Rating</th>
<th>&lt;400 ADT</th>
<th>400-1500 ADT</th>
<th>&gt;1500 ADT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lane Width (ft)</td>
<td>Shld. Width (ft)</td>
<td>Tot. Width (ft)</td>
</tr>
<tr>
<td>1.0</td>
<td>11</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>0.7</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>0.5</td>
<td>9.5</td>
<td>0</td>
<td>9.5</td>
</tr>
<tr>
<td>0.0</td>
<td>9</td>
<td>0</td>
<td>9</td>
</tr>
</tbody>
</table>

![Graph showing Lane Width vs. ADT Rating](image)
Network Level Elements: Cross Slope

- Requires identifying roadway alignment: Tangent – Curve
- Use Table 2-4 in TxDOT’s Roadway Design Manual to determine azimuth change when superelevation becomes required

<table>
<thead>
<tr>
<th>Design Speed</th>
<th>6% Superelevation</th>
<th>8% Superelevation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min. Radius (ft)</td>
<td>Azimuth Δ in 528 ft</td>
</tr>
<tr>
<td>45</td>
<td>6,480</td>
<td>4.67</td>
</tr>
<tr>
<td>50</td>
<td>7,870</td>
<td>3.84</td>
</tr>
<tr>
<td>55</td>
<td>9,410</td>
<td>3.21</td>
</tr>
<tr>
<td>60</td>
<td>11,100</td>
<td>2.73</td>
</tr>
<tr>
<td>65</td>
<td>12,600</td>
<td>2.40</td>
</tr>
<tr>
<td>70</td>
<td>14,100</td>
<td>2.15</td>
</tr>
<tr>
<td>75</td>
<td>15,700</td>
<td>1.93</td>
</tr>
<tr>
<td>80</td>
<td>17,400</td>
<td>1.74</td>
</tr>
</tbody>
</table>

L = 2πR \left( \frac{\theta}{360^\circ} \right)

WHERE:
L = LENGTH OF CURVE ALONG ARC
R = CURVE RADIUS
\theta = DIFFERENCE BETWEEN AZPC AND AZPT
Network Level Elements: Cross Slope

• Within a 0.1-mile data collection section, 528 cross sections exist

• Check the expected location of the highpoint to determine if the section is in-shape
  – Out of shape sections receive a 0.0 rating

• A 50% threshold is required to classify a section as in-shape
Network Level Elements: Tangent Cross Slope
Network Level Elements: Curve Cross Slope

\[ e + f = \frac{V^2}{15R} \]

\[ L = 2\pi R \left( \frac{I}{360°} \right) \]

<table>
<thead>
<tr>
<th>Design Speed (mph)</th>
<th>Max Side Friction factor, ( f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>0.15</td>
</tr>
<tr>
<td>50</td>
<td>0.14</td>
</tr>
<tr>
<td>55</td>
<td>0.13</td>
</tr>
<tr>
<td>60</td>
<td>0.12</td>
</tr>
<tr>
<td>65</td>
<td>0.11</td>
</tr>
<tr>
<td>70</td>
<td>0.10</td>
</tr>
<tr>
<td>75</td>
<td>0.09</td>
</tr>
<tr>
<td>80</td>
<td>0.08</td>
</tr>
</tbody>
</table>
Network Level Elements: Hydroplaning Potential

Extract Drainage Basins from 1 ft x 1 ft LiDAR Data

Find Basin with Largest Area in Wheel Path

Determine Basin Characteristics
- Length of Flow Path
- Avg. Width of Basin
- Slope of Flow Path

Calculate Peak Discharge, Q, using the Rational Method

Calculate Unit Discharge, q

Determine Manning’s n using Reynolds’s Number approach from PAVDRN and TxDOT tabular values

Utilize the continuity equation and Manning’s formula to calculate water depth

Subtract the texture depth from water depth to get WFT

Agency Control Ends Here

Includes vehicle related variables

Use Gallaway and FEM to calculate HPS
Network Level Elements: Hydroplaning Potential

- Monte Carlo simulation for variables within HPS equations
  - AADT used for number of iterations
- Compare against posted speed limit
- Potential reduction in speed of 3 mph to 6 mph in heavy rain
Network Level Elements: Front Slope Steepness

- TxDOT Roadway Design Manual: 1/3 of fatalities associated with single vehicle run-off-the-road
- AASHTO Roadside Design Guide:
  - 1V:4H considered recoverable
  - 1V:3H considered traversable but non-recoverable
  - Steeper considered critical
- 1V:6H is a typical slope within TxDOT
Network Level Elements: Ditch Depth

- Data collected shortly after the mowing cycle
- Assume vegetative height of 6 inches
- No specific design criteria for ditch depth
  - Recommendations for different agencies vary between 2-ft and 3-ft below the paved surface
Network Level Elements: Ditch

Flowline Grade

- Flowline grade rated only based on “too flatness”
- Slopes that are too steep are not given a deduction
- Some steep slopes might be a non-erodible material
- Steep slopes can facilitate erosion, but so does the quantity of water
- Amount of water flowing into the ditch from off ROW is unknown
Network Level Elements: Ditch Flowline Grade

![Graph showing the relationship between Ditch Flowline Slope (%) and Ditch Flowline Slope Rating. The graph includes a line that starts at 0.0% slope with a rating of 0.0 and increases linearly to 1.0% slope with a rating of 0.9, then remains flat at 1.0 for slopes greater than 1.0%.](image-url)
Surface Drainage Rating Summary

Each contribute 1/3

Evenly constructed from Roadway and Roadside
Application of Surface Drainage Rating

• Applied to rural sections with both roadway and roadside elements
• Applied only in the data collection direction
• Proof of concept code developed to create the rating with little manual intervention
  – This is a primary reason for application only to rural roadways
• Applied to 73.5 miles of roadway in the Atlanta, Bryan, Corpus Christi, and Tyler Districts
Section 26:
- 68 Overall Rating
- 60 paved surface rating
- 75 roadside rating
- Paved surface rating affected by out of shape section and narrowness
- Roadside rating affected by shallow ditch with flat flowline slope
FM 31 Example, cont.
Section 41 ON FM 2625
Curve Ratings – FM 2983

Cross Slope rating of 0.0, not because its out of shape, but because of the curve
- 463-ft radius
- 4.12% superelevation
- At 4.12% super:
  - 1980-ft radius required for 1.0
  - 1489-ft radius required for 0.9
  - 837-ft radius requires -15 mph advisory
  - 507-ft radius requires -25 mph advisory
Section 10 on FM 136

- Overall rating of 67
  - Paved rating of 51
    - Narrow (9.8-ft)
    - Poor cross slope (1.3%)
    - High hydroplaning potential (55 mph with 70 mph posted)

- Roadside rating of 83
  - 2.6-ft ditch depth
  - 0.6% flowline slope
  - 13.5:1 average front slope steepness
Network Level Difficulty

• Finding the interface between the roadway and the roadside is critical for additional analysis.
• The algorithm is built upon an analysis window determined if an edgeline is present.
• The algorithm looks for a reflectivity change to delineate pavement and vegetation.

– Vegetation is much more reflective than pavement.
Metro Sections

• Should be treated more similar to project level analysis than network level
  – Need to define the parameters of interest
  – Can easily collect lane width and cross slope
  – Extreme widths limit the ability to collect the necessary data in one data collection run
    • Merging data proves difficult and manually exhausting
    • Hydroplaning potential can be limited by extreme widths
  – Elements such as guard rail and barrier height can be measured if they are specifically needed
Metro Sections – IH 45 Houston
Urban Sections

• Should be treated more similarly to project level analysis than network level analysis
  – Little to no roadside elements
  – Data collection can be impacted by other vehicles
Urban Sections

• More time is spent writing code for exceptions than the actual network level analysis

• Information can be gathered on curb height, location of driveways, and inlets
  – Often requires manual processing and analysis
  – Drainage basins can be developed from automated data collection and gridded data
    • Additional hydraulic calculations can then be performed to evaluate inlet size and outside lane ponding
Urban Section – SH 30 Bryan District
Project Level Analysis

• US 75 – Paris District
  – Detailed design of roadside grading and underdrain system
An underdrain lateral line placed at the 900 m location will have a slope of approx. 5.5%.

An underdrain lateral line placed at the 950 m location will have a slope of approx. 3.75%.

An underdrain lateral line placed at the 840 m location will have a slope of approx. 2.0%. 

Location along Northbound Mainlanes (m)
FM 652 – Project Level Analysis

• Potential “gyp-sink” issues

• Built-in low water crossings with high deflections

• Use mobile LiDAR data to design new roadway profile and corresponding ditch profiles
  – Increase ditch depth without violating front slope steepness requirements
FM 652 – Project Level Analysis
US 77 – Project Level Analysis

- Develop rut maps for potential maintenance work
- Evaluate outside lane rutting with ditch depths
US 77 – Project
Level Analysis

The table contains rut fill locations along US 77

The table on the following slide provides roadside ditch grading information

The final slide associated with US 77 provides an example of a rut map

<table>
<thead>
<tr>
<th>Section No.</th>
<th>Location No.</th>
<th>Begin Disp.</th>
<th>End Disp.</th>
<th>Lane</th>
<th>Wheel Path</th>
<th>Length (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SB1</td>
<td>200</td>
<td>475</td>
<td>Outside SB</td>
<td>Outside</td>
<td>275</td>
</tr>
<tr>
<td></td>
<td>SB2</td>
<td>875</td>
<td>980</td>
<td>Outside SB</td>
<td>Both</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>SB3</td>
<td>2135</td>
<td>2575</td>
<td>Outside SB</td>
<td>Inside</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td>NB1</td>
<td>370</td>
<td>1750</td>
<td>Outside NB</td>
<td>Both</td>
<td>1380</td>
</tr>
<tr>
<td></td>
<td>NB2</td>
<td>2270</td>
<td>2675</td>
<td>Outside NB</td>
<td>Inside</td>
<td>405</td>
</tr>
<tr>
<td>2</td>
<td>SB4</td>
<td>2625</td>
<td>2805</td>
<td>Outside SB</td>
<td>Both</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>SB5</td>
<td>6235</td>
<td>6490</td>
<td>Outside SB</td>
<td>Outside</td>
<td>255</td>
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<tr>
<td>3</td>
<td>NB3</td>
<td>6530</td>
<td>6700</td>
<td>Outside NB</td>
<td>Outside</td>
<td>170</td>
</tr>
<tr>
<td>4</td>
<td>NB4</td>
<td>8630</td>
<td>9510</td>
<td>Outside NB</td>
<td>Outside</td>
<td>880</td>
</tr>
<tr>
<td></td>
<td>SB6</td>
<td>8670</td>
<td>9030</td>
<td>Outside SB</td>
<td>Outside</td>
<td>360</td>
</tr>
<tr>
<td></td>
<td>SB7</td>
<td>9700</td>
<td>10360</td>
<td>Outside SB</td>
<td>Outside</td>
<td>660</td>
</tr>
<tr>
<td></td>
<td>SB8</td>
<td>10825</td>
<td>11125</td>
<td>Outside SB</td>
<td>Outside</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>SB9</td>
<td>11680</td>
<td>11820</td>
<td>Outside SB</td>
<td>Both</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>SB10</td>
<td>12330</td>
<td>12535</td>
<td>Outside SB</td>
<td>Outside</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>NB5</td>
<td>11075</td>
<td>11200</td>
<td>Outside NB</td>
<td>Both</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>NB6</td>
<td>11655</td>
<td>11955</td>
<td>Outside NB</td>
<td>Inside</td>
<td>300</td>
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<tr>
<td></td>
<td>NB7</td>
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<td>12395</td>
<td>Outside NB</td>
<td>Outside</td>
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<td>5</td>
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<td>13130</td>
<td>13420</td>
<td>Outside SB</td>
<td>Outside</td>
<td>290</td>
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<tr>
<td></td>
<td>SB12</td>
<td>13775</td>
<td>13850</td>
<td>Outside SB</td>
<td>Outside</td>
<td>75</td>
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<td>13130</td>
<td>13740</td>
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<td>Outside</td>
<td>610</td>
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<tr>
<td></td>
<td>NB9</td>
<td>14060</td>
<td>14185</td>
<td>Outside NB</td>
<td>Outside</td>
<td>125</td>
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<tr>
<td></td>
<td>SB13</td>
<td>16175</td>
<td>16295</td>
<td>Outside SB</td>
<td>Outside</td>
<td>120</td>
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<td></td>
<td>SB14</td>
<td>17550</td>
<td>18235</td>
<td>Outside SB</td>
<td>Both</td>
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<tr>
<td>7</td>
<td>SB15</td>
<td>18375</td>
<td>18495</td>
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<td>Outside</td>
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<td>19505</td>
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<td>Outside SB</td>
<td>Outside</td>
<td>4640</td>
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<td></td>
<td>NB10</td>
<td>19235</td>
<td>19465</td>
<td>Outside NB</td>
<td>Outside</td>
<td>230</td>
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<tr>
<td></td>
<td>NB11</td>
<td>20075</td>
<td>21005</td>
<td>Outside NB</td>
<td>Outside</td>
<td>930</td>
</tr>
<tr>
<td>8</td>
<td>NB12</td>
<td>21200</td>
<td>22000</td>
<td>Outside NB</td>
<td>Both</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>NB13</td>
<td>22505</td>
<td>23050</td>
<td>Outside NB</td>
<td>Inside</td>
<td>545</td>
</tr>
<tr>
<td></td>
<td>SB17</td>
<td>21440</td>
<td>21685</td>
<td>Outside SB</td>
<td>Inside</td>
<td>245</td>
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<td></td>
<td>SB18</td>
<td>24450</td>
<td>27115</td>
<td>Outside SB</td>
<td>Both</td>
<td>2665</td>
</tr>
<tr>
<td>9</td>
<td>NB14</td>
<td>26035</td>
<td>27000</td>
<td>Outside NB</td>
<td>Outside</td>
<td>965</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## US 77 – Project Level Analysis

<table>
<thead>
<tr>
<th>Grading Location</th>
<th>Roadside</th>
<th>Section</th>
<th>Downstream Point Description</th>
<th>Begin Work Dist. (ft)</th>
<th>End Work Dist (ft)</th>
<th>Flow Direction</th>
<th>Length of Ditch Cleaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Southbound</td>
<td>2</td>
<td>Front slope only area where water exits ROW</td>
<td>2925 (just south of driveway)</td>
<td>3700 (ROW transitions to front slope only)</td>
<td>South at approx. 1.85% fall</td>
<td>775</td>
</tr>
<tr>
<td>2</td>
<td>Southbound</td>
<td>3</td>
<td>Deep Cross Culvert</td>
<td>5850 (just south of driveway)</td>
<td>6850 (at cross culvert)</td>
<td>South at approx. 2.85% fall</td>
<td>1000</td>
</tr>
<tr>
<td>3</td>
<td>Southbound</td>
<td>5</td>
<td>Cross Culvert</td>
<td>11050</td>
<td>12135</td>
<td>South at approx. 1.80% fall</td>
<td>1085</td>
</tr>
<tr>
<td>4</td>
<td>Southbound</td>
<td>8</td>
<td>Large Cross Culvert</td>
<td>18680 (just south of small cross culvert)</td>
<td>20335 (at large cross culvert)</td>
<td>South at approx. 1.3% fall</td>
<td>1655</td>
</tr>
<tr>
<td>5</td>
<td>Southbound</td>
<td>9</td>
<td>Shallow Cross Culvert</td>
<td>21140 (rutter area on ROW)</td>
<td>22215 (at small cross culvert)</td>
<td>South at approx. 0.5% fall</td>
<td>75</td>
</tr>
<tr>
<td>6</td>
<td>Southbound</td>
<td>10</td>
<td>Cross Culvert</td>
<td>23940 (at cross culvert)</td>
<td>24520</td>
<td>North at approx. 1.50% fall</td>
<td>580</td>
</tr>
<tr>
<td>7</td>
<td>Southbound</td>
<td>10</td>
<td>Cross Culvert</td>
<td>24520</td>
<td>25100 (at cross culvert)</td>
<td>South at approx. 2.10% fall</td>
<td>580</td>
</tr>
<tr>
<td>8</td>
<td>Southbound</td>
<td>10</td>
<td>Low spot approaching bridge</td>
<td>25100</td>
<td>26060</td>
<td>South at approx. 1.30% fall</td>
<td>960</td>
</tr>
</tbody>
</table>
US 77 – Project Level Analysis
IH 30 – Project Level Analysis

• Rut measurements along IH 30 – Fairly recent work already showing signs of distress – Produced rut depth tables – Associated location with reference markers
IH 30 – Project Level Analysis
Summary, Recommendations, and Conclusions

• A single laser mobile LiDAR system is capable of creating a network level rating for two lane facilities
  – This rating should apply only to the data collection direction
• 1-ft x 1-ft gridded data effectively and accurately creates a paved surface rating
  – No interpolation is required between points
• 3-ft x 3-ft gridded data effectively and accurately creates a roadside surface rating
  – Typically no interpolation is required until beyond the clear zone
Summary, Recommendations, and Conclusions

• The network level rating captures the following paved surface elements
  – Width
    • Developed from establishing the interface between the paved surface and roadside
    • Deductions based on design criteria
  – Cross slope
    • Accuracy of the LiDAR leads to a stepwise deduction curve based on design standards and climate
  – Hydroplaning potential
    • Created by processing LiDAR data into a gridded format and using a Monte Carlo simulation
Summary, Recommendations, and Conclusions

• The network level rating captures the following roadside elements
  – Front slope steepness
    • Deductions are based design criteria with safety emphasized over drainage
  – Ditch depth
  – Ditch flowline slope
    • Only too flat receives a deduction

• Roadside vegetation presents a target surface for the laser
  – Collect data shortly after mowing cycles or after the first hard freeze when the grass is dormant
Summary, Recommendations, and Conclusions

- Urban and metro sections should be treated similar to project level analyses.
  - These sections present different paved surface elements
  - These sections have little to no roadside impact
  - Basic elements such as lane width and lane cross slope are easily attainable
  - Wide widths, particularly in metro sections can create holes in the data
Summary, Recommendations, and Conclusions

• Mobile LiDAR is a highly effective tool at the project level with manual processing and analysis
  – Rut mapping from data collected at highway speeds
  – Curb height
  – Driveway openings
  – Rut depth and ditch depth comparisons
  – Drainage basin determination for urban hydraulic considerations

• Mobile LiDAR can be used at the project level for detailed preliminary designs
  – Can be used to help create and guide detailed designs
Thank you!

Questions?