Safety Evaluation of Roundabouts in North Carolina

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NCDOT Transportation Mobility & Safety Division

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Evaluation Objectives:
The Purpose of this Evaluation is to Determine the Safety Effectiveness of Roundabouts Installations Statewide

- Crash Frequency
- Severity
- Crash Types
- Night Crashes & Lighting Conditions
- Relationships between Intersection Geometry & Crashes
- Relationships between Entering Volume & Crashes
- Vehicle Speeds
- Signing and Marking Practices
Roundabout Study Locations

54 Total Study Locations
(30 Locations for Before & After)

NCDOT Transportation Mobility & Safety Division
Roundabout Study Locations

- MINI
  Inscribed Circle Diameter
  45’ - 80’

- COMPACT
  Inscribed Circle Diameter
  81’ - 100’

- SINGLE LANE
  Inscribed Circle Diameter
  101’ - 130’

- LARGE SINGLE LANE
  Inscribed Circle Diameter
  > 130’

- TRAFFIC CIRCLE (290°)

- DOUBLE LANE

- RAMP

NCDOT Transportation Mobility & Safety Division
Crash Analysis Results

NCDOT Transportation Mobility & Safety Division
North Carolina Crash Analysis Results
Percent Crash Reductions at NC Roundabouts
(Naïve Before & After with Linear Traffic Factor)

<table>
<thead>
<tr>
<th>Category</th>
<th>All 30 Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Crashes</td>
<td>46.2% (5.2)</td>
</tr>
<tr>
<td>Injury Crashes - All Types</td>
<td>75.3% (4.9)</td>
</tr>
<tr>
<td>Injury Crashes - KAB</td>
<td>85.0% (6.5)</td>
</tr>
<tr>
<td>Frontal Impact Crashes*</td>
<td>75.6% (3.9)</td>
</tr>
<tr>
<td>Rear End Crashes*</td>
<td>29.9% (13.2)</td>
</tr>
<tr>
<td>Sideswipe Crashes*</td>
<td>20.1% (28.9)</td>
</tr>
<tr>
<td>Day</td>
<td>56.0% (5.0)</td>
</tr>
<tr>
<td>Night</td>
<td>2.8% (18.2)</td>
</tr>
</tbody>
</table>

* As crash classified in DMV 349
( ) = standard deviation of an estimated value

NCDOT Transportation Mobility & Safety Division
### National Roundabout Safety Statistics

**SOURCE: NCHRP 672 (2010)**

<table>
<thead>
<tr>
<th>Control Before</th>
<th>Sites</th>
<th>Setting</th>
<th>Lanes</th>
<th>All</th>
<th>Injury + Fatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Sites</td>
<td>55</td>
<td>All</td>
<td>All</td>
<td>35.4% (3.4)</td>
<td>75.8% (3.2)</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>All</td>
<td>All</td>
<td>47.8% (4.9)</td>
<td>77.7% (6.0)</td>
</tr>
<tr>
<td>Signalized</td>
<td>4</td>
<td>Suburban</td>
<td>2</td>
<td>66.7% (4.4)</td>
<td>Sample too small to analyze</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Urban</td>
<td>All</td>
<td>Effects insignificant</td>
<td>60.1% (11.6)</td>
</tr>
<tr>
<td>All-way stop</td>
<td>10</td>
<td>All</td>
<td>All</td>
<td>Effects insignificant</td>
<td>Effects insignificant</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>All</td>
<td>All</td>
<td>44.2% (3.8)</td>
<td>81.8% (3.2)</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Rural</td>
<td>1</td>
<td>71.5% (4.0)</td>
<td>87.3% (3.4)</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>All</td>
<td>1</td>
<td>29.0% (9.0)</td>
<td>81.2% (7.9)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Urban</td>
<td>1</td>
<td>39.8% (10.1)</td>
<td>80.3% (10.0)</td>
</tr>
<tr>
<td>Two-way stop</td>
<td>5</td>
<td>2</td>
<td>All</td>
<td>Sample too small to analyze</td>
<td>Sample too small to analyze</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Suburban</td>
<td>All</td>
<td>31.8% (6.7)</td>
<td>71.0% (8.3)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Suburban</td>
<td>1</td>
<td>78.2% (5.7)</td>
<td>77.6% (10.4)</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td>2</td>
<td>19.3% (9.1)</td>
<td>68.0% (11.6)</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>Urban/Suburban</td>
<td>All</td>
<td>30.8% (5.5)</td>
<td>74.4% (6.0)</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>Suburban</td>
<td>1</td>
<td>56.3% (6.0)</td>
<td>77.7% (7.4)</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Suburban</td>
<td>2</td>
<td>17.9% (8.2)</td>
<td>71.8% (9.3)</td>
</tr>
</tbody>
</table>

Overall, there is an observed reduction of 35% and 76% in total and injury crashes, respectively, following conversion to a roundabout. These values are consistent with results from international studies, as shown in Exhibit 5-10.
Crash Analysis Results - Immediately After

Safety Performance First Year After Installation

<table>
<thead>
<tr>
<th></th>
<th>Total Crashes/ Yr/Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before: Two-Way Stop</td>
<td>2.1</td>
</tr>
<tr>
<td>Before: Signalized</td>
<td>1.9</td>
</tr>
<tr>
<td>After: First Year</td>
<td>0.9</td>
</tr>
<tr>
<td>After: Remainder of After Period</td>
<td>1.2</td>
</tr>
</tbody>
</table>

NCDOT Transportation Mobility & Safety Division
Crash Analysis Results: Crash Types

NCDOT Transportation Mobility & Safety Division
Roundabout Crash Types

- Sideswipe / Turning: 38% (90)
- Rear End: 30% (69)
- Ran Off Road: 25% (57)
- Other: 5% (11)
- Bicycle: 2% (4)

0 Pedestrian Crashes

( ) = Crash Frequency

NCDOT Transportation Mobility & Safety Division
# Bicycle and Pedestrian Involved Crashes

<table>
<thead>
<tr>
<th>Study Years</th>
<th>#</th>
<th>Injury Type</th>
<th>Vehicle Impact Speed</th>
<th>Location</th>
<th>#</th>
<th>Injury Type</th>
<th>Vehicle Impact Speed</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT Weaver @ University Heights</td>
<td>7</td>
<td>1</td>
<td>B</td>
<td>10 mph</td>
<td>inside</td>
<td>0</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>US 421 NB Ramp @ Williams</td>
<td>6</td>
<td>0</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1</td>
<td>B</td>
<td>5 mph</td>
</tr>
<tr>
<td>US 421 SB Ramp @ Williams</td>
<td>9</td>
<td>0</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1</td>
<td>C</td>
<td>15 mph</td>
</tr>
<tr>
<td>Ninth @ Davidson</td>
<td>8</td>
<td>1</td>
<td>B</td>
<td>5 mph</td>
<td>xwalk</td>
<td>0</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Voit Gilmore @ Knoll</td>
<td>4</td>
<td>0</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>1</td>
<td>B</td>
<td>20 mph</td>
</tr>
<tr>
<td>Pullen @ Stinson</td>
<td>6</td>
<td>1</td>
<td>C</td>
<td>5 mph</td>
<td>xwalk</td>
<td>1</td>
<td>C</td>
<td>5 mph</td>
</tr>
<tr>
<td><strong>SUM</strong></td>
<td><strong>3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>4</strong></td>
<td></td>
</tr>
</tbody>
</table>
Heavy Vehicle Involvement

Bus/Truck 7% (17)

Passenger Vehicle 93% (214)

() = Crash Frequency

NCDOT Transportation Mobility & Safety Division
Day Vs. Night Crashes

<table>
<thead>
<tr>
<th>Lighting Condition</th>
<th>% Crash Reduction With Linear Traffic Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>56.0% (5.0)</td>
</tr>
<tr>
<td>Night</td>
<td>2.8% (18.2)</td>
</tr>
</tbody>
</table>

( ) = standard deviation of an estimated value
Crash Analysis Results:
Intersection Features & Crashes
## Crash Analysis Results – Size Categories

### Percent Crash Reductions at NC Roundabouts
(Naïve Before & After with Linear Traffic Factor)

<table>
<thead>
<tr>
<th>SINGLE LANE</th>
<th>Sites</th>
<th>Total Crashes</th>
<th>KAB Injury Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini &amp; Compact</td>
<td>9</td>
<td>60.7% (7.5)</td>
<td>100%</td>
</tr>
<tr>
<td>Mini</td>
<td>4</td>
<td>57.7% (17.1)</td>
<td>100%</td>
</tr>
<tr>
<td>Compact</td>
<td>5</td>
<td>61.9% (8.1)</td>
<td>100%</td>
</tr>
<tr>
<td>Standard &amp; Large</td>
<td>14</td>
<td>56.3% (6.3)</td>
<td>84.8% (9.0)</td>
</tr>
<tr>
<td>Standard</td>
<td>10</td>
<td>58.9% (7.3)</td>
<td>90.5% (9.0)</td>
</tr>
<tr>
<td>Large</td>
<td>4</td>
<td>51.4% (12.1)</td>
<td>80.7% (13.6)</td>
</tr>
</tbody>
</table>
Crash Analysis Results – Size Categories

Percent Crash Reductions at NC Roundabouts
(Naïve Before & After with Linear Traffic Factor)

<table>
<thead>
<tr>
<th>Size Categories</th>
<th>Sites</th>
<th>Total Crashes</th>
<th>KAB Injury Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Lane (All, Non-Ramp)</td>
<td>23</td>
<td>57.8% (4.9)</td>
<td>89.6% (6.1)</td>
</tr>
<tr>
<td>Double Lane</td>
<td>1</td>
<td>-11.2% (42.1)</td>
<td>N/A</td>
</tr>
<tr>
<td>Ramp</td>
<td>6</td>
<td>2.5% (19.8)</td>
<td>75.8% (14.5)</td>
</tr>
</tbody>
</table>
### Percent Crash Reductions at NC Roundabouts (Naïve Before & After with Linear Traffic Factor)

<table>
<thead>
<tr>
<th>Control Type</th>
<th>Sites</th>
<th>Total Crashes</th>
<th>KAB Injury Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-Way Stop</td>
<td>24</td>
<td>47.7% (5.7)</td>
<td>78.1% (9.6)</td>
</tr>
<tr>
<td>Signalized</td>
<td>6</td>
<td>41.2% (11.8)</td>
<td>100%</td>
</tr>
</tbody>
</table>
Crash Analysis Results – Number of Legs

Percent Crash Reductions at NC Roundabouts (Naïve Before & After with Linear Traffic Factor)

<table>
<thead>
<tr>
<th>Number of Legs</th>
<th>Sites*</th>
<th>Total Crashes</th>
<th>KAB Injury Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Leg</td>
<td>8</td>
<td>57.1% (9.7)</td>
<td>89.3% (10.1)</td>
</tr>
<tr>
<td>4 Leg</td>
<td>15</td>
<td>58.2% (5.6)</td>
<td>90.2% (6.9)</td>
</tr>
</tbody>
</table>

* All Sizes of Single Lane, Non-Ramp Roundabouts
## Crash Analysis Results – Bypass Lanes

<table>
<thead>
<tr>
<th></th>
<th>Sites</th>
<th>Before</th>
<th>After</th>
<th>Avg. AADT (Excluding Ramps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bypass Lane</td>
<td>5</td>
<td>0.2</td>
<td>0.1</td>
<td>10,800</td>
</tr>
<tr>
<td>No Bypass Lane</td>
<td>25</td>
<td>0.1</td>
<td>0.1</td>
<td>8,000</td>
</tr>
</tbody>
</table>

NCDOT Transportation Mobility & Safety Division
Crash Analysis Results:
Entering Volume & Crashes

NCDOT Transportation Mobility & Safety Division
Comparison of Single Lane Roundabouts, All-Way Stops, Two-Way Stops & Signals

Entering Volume vs. Crashes/Yr

Intersection AADT vs. Total Crashes Per Year (Single Lane Roundabouts)

- Signals: $R^2 = 0.356$
- All-Way Stops: $R^2 = 0.2115$
- Two-Way Stops: $R^2 = 0.0227$
- Single Lane Roundabouts: $R^2 = 0.257$
Entering Volume vs. Crashes/Yr
Comparison of Multi Lane Roundabouts, 2-Way Stops & Signals

Intersection AADT vs. Total Crashes Per Year (Multi Lane Roundabouts)

- Multi Lane Roundabouts: $R^2 = 0.8421$
- Two-Way Stops: $R^2 = 0.2145$
- Signals: $R^2 = 0.115$

Total Crashes Per Year (After Period)
Intersection AADT (Thousands)
Crash Analysis Results:
Speed Related Data
## Crash Analysis Results - Speed Limits

### Percent Crash Reductions at NC Roundabouts
(Naïve Before & After with Linear Traffic Factor)

<table>
<thead>
<tr>
<th>Approach Speed Limits</th>
<th>Sites</th>
<th>Total Crashes</th>
<th>KAB Injury Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Speed (&lt; 45 mph)</td>
<td>19</td>
<td>39.9% (7.9)</td>
<td>90.9% (6.4)</td>
</tr>
<tr>
<td>High Speed (≥ 45 mph)</td>
<td>11</td>
<td>52.6% (6.7)</td>
<td>79.0% (11.1)</td>
</tr>
<tr>
<td>Estimated Speeds at Crash Impact (30 Sites)</td>
<td>Before</td>
<td>After</td>
<td>% Difference</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>--------</td>
<td>-------</td>
<td>--------------</td>
</tr>
<tr>
<td>Average Speed</td>
<td>18.2</td>
<td>15.1</td>
<td>-17%</td>
</tr>
<tr>
<td>Average Speed: Vehicle 1</td>
<td>16.8</td>
<td>16.4</td>
<td>-2%</td>
</tr>
<tr>
<td>Average Speed: Vehicle 2</td>
<td>19.7</td>
<td>13.3</td>
<td>-32%</td>
</tr>
<tr>
<td>Max Speed</td>
<td>70</td>
<td>55</td>
<td></td>
</tr>
</tbody>
</table>

*IQR is the range of the middle 50% of data.
02 The Circular Intersection (W2-6) symbol sign (see Figure 2C-9) may be installed in advance of a circular intersection (see Figures 2B-21 through 2B-23).

Guidance:

03 If an approach to a roundabout has a statutory or posted speed limit of 40 mph or higher, the Circular Intersection (W2-6) symbol sign should be installed in advance of the circular intersection.

Option:

04 An educational plaque (see Figure 2C-9) with a legend such as ROUNDBOUGHT (W16-17P) or TRAFFIC CIRCLE (W16-12P) may be mounted below a Circular Intersection symbol sign.
NC Advanced Warning Sign Practices

NCDOT Transportation Mobility & Safety Division
NC Advanced Warning Sign Practices
Section 2C.08 Advisory Speed Plaque (W13-1P)
Option:

01 The Advisory Speed (W13-1P) plaque (see Figure 2C-1) may be used to supplement any warning sign to indicate the advisory speed for a condition.

Standard:

02 The use of the Advisory Speed plaque for horizontal curves shall be in accordance with the information shown in Table 2C-5. The Advisory Speed plaque shall also be used where an engineering study indicates a need to advise road users of the advisory speed for other roadway conditions.

03 If used, the Advisory Speed plaque shall carry the message XX MPH. The speed displayed shall be a multiple of 5 mph.

04 Except in emergencies or when the condition is temporary, an Advisory Speed plaque shall not be installed until the advisory speed has been determined by an engineering study.

05 The Advisory Speed plaque shall only be used to supplement a warning sign and shall not be installed as a separate sign installation.

06 The advisory speed shall be determined by an engineering study that follows established engineering practices.
Advisory Speed Limits

NCHRP 672 Roundabout Guide (2010):

MUTCD. In practice it is difficult to define an appropriate advisory speed: Should it be related to the slowest speed for through traffic (V2), the slowest speed of all movements (typically V4), or another speed (such as zero for potentially coming to a stop at the yield sign)? In addition, advisory speed plaques are usually only used for turns and curves, not intersections.
Average Crashes Per Year at Sites With and Without Advisory Speed Limits

- Ramp with Advisory Speed: 2.4 (20 mph)
- Ramp without Advisory Speed: 1.6 (None)
- High Speed with Advisory: 1.3 (15 mph 20 mph)
- High Speed without Advisory: 0.9 (None)
- Low Speed with Advisory Speed: 0.9 (10 mph 15 mph 20 mph)
- Low Speed without Advisory Speed: 0.8 (None)
Number of Signs Per Approach

Number of Signs Vs. Crashes Per Year (37 Single Lane Sites, Excluding Minis & Ramps)

- Low Volume & Low Speed
- Low Volume & High Speed
- High Volume & Low Speed
- High Volume & High Speed

Average Number of Signs Per Approach

Total Crashes Per Year

0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50

1 2 3 4 5 6 7 8
ENGLISH STANDARD DRAWING FOR
TYPICAL PARTIAL LAYOUT OF A RURAL ROUNDABOUT
CROSSING WITH NO PEDESTRIAN PRESENCE

STATE OF NORTH CAROLINA
DEPT. OF TRANSPORTATION
DIVISION OF HIGHWAYS
RALEIGH, N.C.

POSTED SPEED D
<45 mph 125 ft
45 mph 175 ft
50 mph 250 ft
55 mph 325 ft

NOTES:
1. OPTIONAL SIGNS ARE TO BE INSTALLED AT THE DISCRETION OF THE DIVISION ENGINEER.
2. ALL SIGNS SHALL BE FIELD LOCATED BY THE ENGINEER.
3. THE MUTCD PROVIDES DIMENSION "D" IN TABLE 2C-4. THE DISTANCES CONTAINED IN TABLE 2C-4 ARE FOR GUIDANCE PURPOSES AND SHOULD BE APPLIED WITH ENGINEERING JUDGEMENT.
4. THE MUTCD PROVIDES MINIMUM SIGN SIZES IN TABLE 2B-1 (REGULATORY SIGNS) AND 2C-2 (WARNING SIGNS).
Rural Signing & Marking Examples
ENGLISH STANDARD DRAWING FOR
TYPICAL PARTIAL LAYOUT OF AN URBAN ROUNDBOAT
CROSSING WITH PEDESTRIAN PRESENCE

STATE OF
NORTH CAROLINA
DEPT. OF TRANSPORTATION
DIVISION OF HIGHWAYS
RALEIGH, N.C.

POSTED SPEED D
<45 mph 125 ft
45 mph 175 ft
50 mph 250 ft
55 mph 325 ft

NOTES:
1. OPTIONAL SIGNS ARE TO BE INSTALLED AT THE DISCRETION OF THE
DIVISION ENGINEER.
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4. THE MUTCD PROVIDES MINIMUM SIGN SIZES IN TABLE 2B-1 (REGULATORY
SIGNS) AND 2C-2 (WARNING SIGNS).
Pedestrian Accommodations
Pedestrian Accommodations
Pedestrian Accommodations
Bicycle Accommodations
### Pavement Marking Practices

<table>
<thead>
<tr>
<th>Marking Type</th>
<th>% of Roundabouts [#]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Entry Lines</td>
<td>72% [39]</td>
</tr>
<tr>
<td>Dashed Entry Lines</td>
<td>72% [39]</td>
</tr>
<tr>
<td>“Yield” Markings</td>
<td>6% [3]</td>
</tr>
<tr>
<td>Advance Arrow Markings</td>
<td>13% [7]</td>
</tr>
<tr>
<td>In Circle Arrow Markings</td>
<td>19% [10]</td>
</tr>
<tr>
<td>Marked Crosswalks</td>
<td>59% [32]</td>
</tr>
</tbody>
</table>
Collision Diagrams

NCDOT Transportation Mobility & Safety Division
Crash Diagrams: Westview @ Buckingham, Forsyth Co.

MINI SINGLE LN

BEFORE (8 Years of Data)
Crash Diagrams: Westview @ Buckingham, Forsyth Co.

**MINI SINGLE LN**

**AFTER (8 Years of Data)**
Crash Diagrams: WT Weaver @ University Heights, Buncombe Co.

COMPACT SINGLE LN

BEFORE (7 Years of Data)
Crash Diagrams: WT Weaver @ University Heights, Buncombe Co.

COMPACT SINGLE LN

AFTER (7 Years of Data)
Crash Diagrams: NC 751 @ Erwin Rd, Durham Co.

COMPACT SINGLE LN WITH BYPASS LN

BEFORE (6 Years of Data)
Crash Diagrams: NC 751 @ Erwin Rd, Durham Co.

COMPACT SINGLE LN WITH BYPASS LN

AFTER (6 Years of Data)
Crash Diagrams: Lake Jeanette @ Elm, Guilford Co.

STANDARD SINGLE LANE

BEFORE (3 Years of Data)
Crash Diagrams: Lake Jeanette @ Elm, Guilford Co.

STANDARD SINGLE LANE

AFTER (3 Years of Data)
Crash Diagrams: Gaston Day School @ Kendrick, Gaston Co.

STANDARD SINGLE LANE

BEFORE (4 Years of Data)
Crash Diagrams: Gaston Day School @ Kendrick, Gaston Co.

STANDARD SINGLE LANE

AFTER (4 Years of Data)
Crash Diagrams: Ninth @ Davidson, Mecklenburg Co.

LARGE SINGLE LANE

BEFORE (8 Years of Data)
Crash Diagrams: Ninth @ Davidson, Mecklenburg Co.

LARGE SINGLE LANE

AFTER (8 Years of Data)
Crash Diagrams: US 421 @ Williams Rd, Forsyth Co.

INTERCHANGE

BEFORE (9 Years of Data)  BEFORE (6 Years of Data)
Crash Diagrams: US 421 @ Williams Rd, Forsyth Co.

INTERCHANGE

AFTER (9 Years of Data)

AFTER (6 Years of Data)
Crash Diagrams: Main @ Salem, Forsyth Co.

BEFORE (4 Years of Data)
Crash Diagrams: Main @ Salem, Forsyth Co.

AFTER (4 Years of Data)
CONCLUSION

Recommended Crash Reduction Factors:

<table>
<thead>
<tr>
<th>Category</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Crashes</td>
<td>-46%</td>
</tr>
<tr>
<td>Injury Crashes</td>
<td>-75%</td>
</tr>
<tr>
<td>Frontal Impact Crashes</td>
<td>-76%</td>
</tr>
</tbody>
</table>

NCDOT Transportation Mobility & Safety Division
QUESTIONS?

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