APPENDIX A
Analysis of Roundabout Analytical Models During Unbalanced Flows Using Bluetooth Mac Address Matching

Unbalanced Flows Using Bluetooth Mac Address

Analysis of Roundabout Analytical Models During

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Case 1: Control Delay without Queue Delay

- No Control Device
- Control Device Present

Distance Through Corridor vs. Time

Roundabout Present

Control Device

No Control Device
Case 2: Control Delay with Queue Delay

- No Control
- Device Present

Distance Through Corridor vs. Time

- Roundabout
- Control Device
- No Control Device
What Users Care About

Distance in Route (Feet) vs. Transit Time (Seconds)

- LARGE Control Delay
- SMALL Control Delay
- Queue Delay
- Free Flow Speed

The graphs illustrate the relationship between distance and transit time, highlighting how users perceive control delays and queues in terms of their impact on travel time.
Engineering Challenge

Predicting This...

Transit Time (Seconds)

Distance in Route (Feet)

45 Miles Per Hour (Free Flow Speed)
Delay Concept

BLUETOOTH CONTROL DELAY
\[ d = t_2 - t_1 - \frac{\text{Distance}}{v_{ffs}} \]

HCM CONTROL DELAY
\[ d = \frac{3,600}{c} + 900T \left[ x - 1 + \sqrt{(x - 1)^2 + \frac{\left( \frac{3,600}{c} \right)^x}{450T}} \right] + 5 \times \min[x,1] \]
Delay Concept

Distance in Route (Feet)

Transit Time (Seconds)

45 Miles per Hour (Free Flow Speed)
86 Seconds (Free Flow Travel Time)

Deceleration
Queue
Acceleration

Deceleration
Queue
Acceleration
Average Control Delay

HCM 2010

\[
d = \frac{3,600}{c} + 900T \left[ x - 1 + \sqrt{(x - 1)^2 + \left( \frac{3,600}{c} \right) x} \right] + 5 \times \min[x,1]
\]

where

\[d = \text{average control delay, s/veh;}
\]

\[x = \text{volume-to-capacity ratio of the subject lane;}
\]

\[c = \text{capacity of subject lane, veh/h; and}
\]

\[T = \text{time period, h (} T = 1 \text{ for a 1-hour analysis, } T = 0.25 \text{ for a 15-minute analysis).}
\]
Single-Lane Roundabouts

HCM 2010

\[ c_{pce} = 1,130e^{(-1.0 \times 10^{-3})v_{c, pce}} \]

where

- \( c_{pce} \) = lane capacity, adjusted for heavy vehicles, pc/h; and
- \( v_{c, pce} \) = conflicting flow, pc/h.
Spring Mill Road at 106th/116th Street

Carmel, Indiana
Carmel, Indiana

Spring Mill Road at 116th Street
Carmel, Indiana
Spring Mill Road at 106th Street
Carmel, Indiana
NuMetrics Counters

![Map of Carmel, Indiana with NuMetrics Counters locations marked: C8 (SB), C5 (SB), C5 (EB), C4 (NB).]
Counter Summary
Spring Mill Road at W 106th Street

Monday, April 26, 2010
Southbound

Tuesday, April 27, 2010
Counter Summary
Spring Mill Road at W 106th Street

Monday, April 26, 2010
Tuesday, April 27, 2010

Southbound
AM Peak

CAM-191 M
Deploy Bluetooth Devices to Measure Travel Time and Delay

BLUETOOTH DATA COLLECTION
Carmel, Indiana
Bluetooth Cases
Determine Baseline Travel Time

Convert Measured Travel Time to Delay

\[
\frac{4,092' + 79' + 1,478'}{45 \text{ mph}} = 86 \text{ Seconds}
\]
Determine Baseline Travel Time

Convert Measured Travel Time to Delay

Approach

Setback (ft)

WB 932
NB 2,404
EB 4,092
SB 1,478

Movement

Delta TT (s)

WB-L 270 54
WB-T 180 79
WB-R 90 38
NB-R 90 52
NB-L 270 102
NB-T 180 61
EB-T 180 79
EB-R 90 100
EB-L 270 88
SB-L 270 40
SB-T 180 61
SB-R 90 86

\[
\text{mph} = \frac{\text{seconds}}{86 \text{ seconds}} = 45 \text{ mph}
\]

\[
\text{Baseline Travel Time} = \frac{360 \times 100 \times \pi}{90} = 4', 092', 79', 478'
\]

\[
\text{Time to Delay} = 4', 092', 79', 478'
\]
Travel Time Data
No Baseline Offset Applied
Delay Time
Baseline Travel Time Subtracted

Delay Time (Seconds)

Left Thru Right

C3 (WB)
W 106th Street (Westbound)
5-day Work Week
W 106th Street (Westbound)
Aggregated Composite Weekday

Delay Time (Seconds)

0:00 6:00 12:00 18:00 0:00
Compare Modeled Delay with Field Measured Data
Scale Entering Volume

Determine Movement Fraction

Ve = 200

NuMetrics NC-200

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<th>Value</th>
<th>NB-L</th>
<th>NB-T</th>
<th>NB-R</th>
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<tr>
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<td>6</td>
<td>4</td>
<td>10</td>
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<td>Bluetooth %</td>
<td>30</td>
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<tr>
<td>Movement #</td>
<td>60</td>
<td>40</td>
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W 106th Street (Westbound)
Measured Delay vs. HCM Delay
Spring Mill Road (Northbound)

Measured Delay vs. HCM Delay

Delay Time (Seconds)
W 106th Street (Eastbound)
Measured Delay vs. HCM Delay

Delay Time (Seconds)

0:00 6:00 12:00 18:00 0:00

C5 (EB)

APRIL

S M T W T F S
1 2 3
4 5 6 7 8 9 10
11 12 13 14 15 16 17
18 19 20 21 22 23 24
25 26 27 28 29 30

S M T W T F S
1 2 3
4 5 6 7 8 9 10
11 12 13 14 15 16 17
18 19 20 21 22 23 24
25 26 27 28 29 30

Spring Rd
Clarian Medical
Center of Indiana
Spring Mill Road (Southbound)
Measured Delay vs. HCM Delay
Delay Concept

Distance in Route (Feet) vs. Transit Time (Seconds)

BLUETOOTH CONTROL DELAY:

$$d = t_2 - t_1 - \left(\frac{\text{Distance}}{v_{ffs}}\right)$$

HCM CONTROL DELAY:

$$d = \frac{3,600}{c} + 900T \left[ x - 1 + \sqrt{(x - 1)^2 + \left(\frac{3,600}{c}T\right)^2}\right] + 5 \times \min[x,1]$$
Summary of Comparison

Measured Delay vs. HCM Delay

The graph shows a comparison of measured delay time versus HCM modeled delay time for different directions (Northbound, Eastbound, Westbound, and Southbound). The data points are scattered across the graph, indicating a range of measured delays compared to modeled delays. The axes represent the probe vehicle measured delay time (seconds) on the y-axis and HCM modeled delay time (seconds) on the x-axis. The graph includes markers for each direction, allowing for a visual comparison of delay times across different directions.
What Users Cares About

![Graph showing distance in route (feet) vs. transit time (seconds) for two scenarios: LARGE Control Delay and SMALL Control Delay. The graph illustrates how users' perceptions change with different control delays, indicating a thumbs-down for large delays and a thumbs-up for small delays.](image-url)