NCHRP Report 772: Evaluating the Performance of Corridors with Roundabouts

Transportation Education Series
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Contractors

• Kittelson & Associates, Inc.
  – Lee Rodegerdts - Principal Investigator
  – Brian Ray, Pete Jenior, Zachary Bugg
• Institute for Transportation Research & Education (North Carolina State University)
  – Bastian Schroeder
• Texas Transportation Institute (Texas A&M University)
  – Marcus Brewer
• Write Rhetoric
  – Danica Rhoades
Project Panel

- Phil Demosthenes, consultant (chair)
- Stephen Bass, Kansas DOT
- Wylie Bearup, City of Phoenix, AZ
- Sarah Bowman, Walkable Communities, Inc.
- Robert Fenton, Ohio State University
- Theron Knause, Virginia DOT
- Mark Lenters, Ourston Roundabout Engineering, Inc.
- Avijit Maji, Maryland State Highway Administration
- Dina Swires, Washington State DOT
- Rich Cunard, TRB
- Hillary Isebrands, FHWA
- Lori Sundstrom, NCHRP Program Officer

Presentation overview

- Project objective
- Project scope
- Corridors and data collection
- Project products
Project Objective

• Focus on three or more roundabouts in series

Photo: Lee Rodrigues

Project Scope

• Document existing roundabout corridors
  – Collect and evaluate field data
  – Identify “lessons learned” from agencies
• Prepare methods and guidance for alternatives evaluations
  – Prepare predictive methods based on observed field data for incorporation into key resource documents such as HCM
  – Prepare “Corridor Comparison Document” to demonstrate broader evaluation process
Site Selection

- 58 roundabout corridors identified in US (as of 2011)
- Nine corridors selected
- Geographically dispersed across the U.S., with some grouping for data collection efficiency
- Mix of urban, suburban, and rural environments
- Mix of single-lane and multilane roundabouts
- Wide range of circumstances leading to each corridor

Roundabout Corridors in US (as of 2011)
Data Collection Corridors

- MD 216, Scaggsville, MD (pilot study site)
- La Jolla Boulevard, San Diego, CA (pilot study site)
- Old Meridian Street, Carmel, IN
- Spring Mill Road, Carmel, IN
- Borgen Boulevard, Gig Harbor, WA
- SR 539, Whatcom County, WA
- Golden Road, Golden, CO
- Avon Road, Avon, CO
- SR 67, Malta, NY

Data Collection Methods

- Travel time runs using GPS
- Bluetooth™ data collection (pilot sites only)
- Video recording of intersections (primarily for peak hour turning movement extraction)
- Spot speed samples
- Photographs and field notes
- Interviews with corridor owners/operators

- Data collection methods refined after pilot study locations (focused on GPS instead of Bluetooth)
Example Time-Space Trajectory
(La Jolla Boulevard SB, San Diego, CA)

Example Speed Profile for Urban Corridor
(La Jolla Boulevard SB, San Diego, CA)
Old Meridian Street, Carmel, Indiana

Spring Mill Road, Carmel, Indiana
Example Speed Profile for Rural Corridor
(SR 539 NB, Whatcom County, WA)

Golden Road, Golden, Colorado
Example Speed Profile through Interchange (SR 67 EB, Malta, NY)

Corridor Owner/Operator Interviews

- Wide variety of experiences leading to development of corridors
- Reinforces motivation of Corridor Comparison Document to evaluate corridors on case-by-case basis
Corridor Owner/Operators – Lessons Learned

- Once several roundabouts built on a corridor, more are likely
  - Increased acceptance of roundabouts
  - Concerns about signal queue spillback
  - Access management
  - Consistency within corridor
- Traffic analysis typically analyzed roundabouts in isolation
- Agency champion is key

Modeling

- New predictive tools for estimating operational performance of roundabout corridors
- Created for incorporation into HCM to enable signals-versus-roundabouts predictive comparisons
- Process of incorporating into HCM is underway with development of HCM 2010 Major Update
Modeling Framework

- New models developed by this project:
  - Free-flow speed (Step B)
  - Roundabout Influence Area Length (Step C)
  - Geometric Delay (Step H)
  - Impeded Delay (Step I) – analogous to control delay
- Fits into existing Urban Streets Procedure
Segment and Sub-Segment Definitions

Operations Comparisons with “Equivalent Signalized Corridors”

- High-level comparison to suggest trends if any
- “Equivalent” signalized corridors developed for each roundabout corridor
- Estimate travel time (TT) performance using HCM-based and simple simulation-based analysis
- Compare estimated TT to field-measured roundabout performance
Operations Comparisons with “Equivalent Signalized Corridors” (cont.)

- Neither control option consistently results in reduced travel time or delay for through routes
- Site-specific evaluation is key
- Roundabouts tends to improve travel time for routes with a left turn onto or off a corridor
- Roundabouts are more likely to improve travel time with irregular intersection spacing

Corridor Comparison Document

- Chapter 1: Introduction
- Chapter 2: Users of Arterials
- Chapter 3: Project Planning Process
  - 3.1 Project Initiation (incl. understanding of context)
  - 3.2 Concept Development
  - 3.3 Alternatives Analysis
- Chapter 4: Performance Measures
- Chapter 5: Example Applications
Understanding of Context

- Select performance metrics that are important for the corridor being studied
- Develop and evaluate reasonable alternatives

Potential Performance Measures

- Categories:
  - Quality of Service
  - Safety
  - Environmental
  - Costs
  - Community Values
  - Other

Performance Measures

- Quality of Service
  - Intersection delay
  - Speed
  - Capacity
- Safety
  - Pedestrian and bicycle impacts on auto traffic
  - Delay to left-turn movements
- Environmental
  - Air quality
- Costs
  - User costs
  - Annual maintenance cost
- Community Values
  - Accessibility
- Other
  - Functionality
  - Aesthetics
Example Applications

• Show use of:
  – Corridor Comparison Document
  – Roundabout travel time model developed for this project

• Examples
  – New suburban greenfield corridor
  – Community enhancement on existing urban corridor
  – Existing rural corridor in context sensitive, suburbanizing area
  – Existing suburban corridor undergoing operations and safety evaluation

Questions?
Motivation for Research

- Roundabouts are one of FHWA’s Nine Proven Countermeasures
- Nearly 15 years since first edition of Roundabouts: An Informational Guide, roundabouts have yet to be fully embraced by many agencies
- FHWA observed need for strategic undertaking to accelerate roundabout implementation
Goal of TOPR 34

- Uncertainty about a small number of key issues seemed to be hampering more widespread roundabout implementation
- FHWA well-positioned to undertake evaluations of these key issues that will result in better guidance to practitioner community
- Emphasis on real world, field-based data

TOPR 34 Tasks

- Assessment of Rectangular Rapid Flashing Beacons (RRFB) for accessibility at multilane roundabouts
- Reassessment of capacity models for the Highway Capacity Manual
- Assessing emissions characteristics of roundabouts compared to signalized intersections
- Evaluation of fatal and severe injury crashes
TOPR 34 Tasks (cont.)

- Evaluation of geometric parameters for trucks
- Assessment of crosswalk location and design
- Assessment of traffic control device treatments at multilane roundabouts

Contractors

- Virginia Tech Transportation Institute
  - Ron Gibbons, Contract Manager
- Kittelton & Associates, Inc.
  - Lee Rodegerdts, Principal Investigator
- Institute of Transportation Research and Education (ITRE) at North Carolina State University
  - Bastian Schroeder, Co-Principal Investigator
- Task Leaders from all three organizations
Motivation for Research

- New capacity models for roundabouts added to HCM 2010 based on NCHRP Report 572 (2007)
- Concern throughout user community that capacities are lower than currently being observed
- Results of perceived capacity underestimation is either oversizing roundabouts or avoiding them altogether
Purpose of Research Effort

- Collect new set of national field data (2012-2013)
  - NCHRP Report 572 data: 2003
- Determine fit of HCM 2010 model to new data
- Determine best course of action to improve fit as needed within constraints of time and budget:
  - Calibrate using critical headway and follow-up time
  - Develop new exponential or linear regression model
  - Identify flow-based or geometric-based factors if beneficial in improving model fit

Site Selection

- 23 intersections across the United States:
  - Colorado (5)
  - Indiana (7, all in Carmel)
  - New York (2)
  - Virginia (1)
  - Vermont (1)
  - Washington (7)
- Each approach studied at a given intersection is considered a “site” for this analysis
Data Collection

• Video recording of 48 hours at each site (2012-2013)
• Cameras focused on entering-circulating-exiting area
• Back of queue not always observed
  – Camera angles
  – Saturated but slowly rolling queues

Conditions for Data to be Usable

• Looking only for data periods that represent capacity conditions: continuous queuing over the entire study interval (1 min)
• Two criteria examined:
  – Minimum queue recorded (where possible)
  – Maximum move-up time <= 6 s
    • Camera angle prevented visibility of queue, or
    • Conditions saturated but rolling queue
• Generally consistent with NCHRP Report 572 methods
Usable Data for Capacity Analysis

- Single-lane sites: 876 minutes
- Multilane sites: 1,285 minutes (all types)
  - Multilane 1x2: 56
  - Multilane 2x1: 231 right lane, 288 left lane
  - Multilane 2x2: 365 right lane, 345 left lane

- NCHRP Report 572: single-lane 318 minutes, multilane 383 minutes (all types)
- Significantly larger dataset than for NCHRP Report 572

Fit of HCM 2010 Model: Single-Lane

HCM 2010: RMSE = 216
Fit of HCM 2010 Model: 2x2 Right Lane

**HCM 2010:**

\[ \text{RMSE} = 183 \]

Fit of HCM 2010 Model: 2x2 Left Lane

**HCM 2010:**

\[ \text{RMSE} = 218 \]
Fit of HCM 2010 Model: 2x1 Right Lane

HCM 2010: RMSE = 255

Fit of HCM 2010 Model: 2x1 Left Lane

HCM 2010: RMSE = 224
Modeling Techniques

- Basic model forms analyzed:
  - Exponential: \( v_e = Ae^{-Bv_c} \)
  - Linear: \( v_e = A - Bv_c \)
- Gap acceptance parameters for HCM 2010 calibration (measured under queued conditions)
  - Critical Headway \( (t_c) \)
  - Follow-Up Time \( (t_f) \)
- Model parameters set to minimize Root Mean Square Error (RMSE) when allowed to vary

Example of Regression: Single-Lane Sites

![Graph showing regression analysis](image)
Follow-Up Time Field Measurements

- Measured under queued conditions
- Outliers greater than mean + 3 s.d. removed
- Intercept $A = \frac{3600}{t_f}$

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<th>Number Observations</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Intercept</th>
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<td>1x2</td>
<td>318</td>
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</table>

Single-Lane Sites: Calibrated to National Follow-Up Time

Exp. Regression: $RMSE = 190$
Linear Regression: $RMSE = 223$
2x2 Right Lane: Calibrated to National Follow-Up Time

Exp. Regression: 
RMSE = 164
Linear Regression: 
RMSE = 192

2x2 Left Lane: Calibrated to National Follow-Up Time

Exp. Regression: 
RMSE = 214
Linear Regression: 
RMSE = 243
Geometric Effects

• Explored relationships between follow-up time and key geometric parameters:
  – Inscribed circle diameter
  – Entry lane width
  – Entry angle
  – Splitter island width (for exiting effect)
• Conclusion: Trends are apparent but not strong enough to include in the capacity model
Geometric Effects (cont.)

Follow-Up Time vs. Entry Lane Width

- Trends in intuitive direction but too weak to use
  
  Correlation = 0.24
  $R^2 = 0.06$

Follow-Up Time vs. Splitter Island Width

Follow-Up Time vs. Entry Angle
Summary of Findings

- Calibration to national follow-up time generally produces plausible results with means for calibration
- Adjustment made to 2x1 model for better fit
- Exponential form fits same or better than linear form in all cases
- Separate investigation found that calibration to local follow-up time produces best fit of all models to date
Recommended Candidate Models

• Single-lane model: $v_e = 1380 \exp(-0.00102 \, v_c)$
• 2x2 right lane: $v_e = 1420 \exp(-0.00085 \, v_c)$
• 2x2 left lane: $v_e = 1350 \exp(-0.00092 \, v_c)$
• 2x1 both lanes: $v_e = 1420 \exp(-0.00091 \, v_c)$
• 1x2: Use 2x2 right lane model
• Calibrate using local follow-up time where possible

• NOTE: Updated HCM chapters anticipated for adoption by the TRB Committee on Highway Capacity and Quality of Service in June 2015

Questions?

• Lee Rodegerdts, lrodegerdts@kittelson.com