Introduction to Roundabout Analysis Using ARCADY

Toronto SimCap User Group Technical Event
and ITE Toronto Section Social Event
July 22, 2014

Phil Weber, P.Eng.
GHD Inc.
(The Home of Ourston Roundabout Engineering)
What is ARCADY?

- ARCADY is a program for analyzing the capacity and safety performance of roundabouts for motorists.
- It is produced by TRL Software in the U.K.
- ARCADY and PICADY are components of the modular Junctions package for designing and modelling unsignalized intersections (including roundabouts).
- Other TRL Software packages include OSCADY PRO for isolated traffic signal optimization and TRANSYT for network analysis.
What is ARCADY Based On?

- ARCADY is based on three decades of research and development by the TRL for predicting capacities, queues, delays (queuing and geometric) and accident risk at roundabouts.
- It uses capacity and safety equations developed by the TRL in the 1970’s (the “Kimber” equations).
- It also contains the 2010 HCM (Highway Capacity Manual) roundabout capacity model for use where required in U.S. markets.
Background
Roundabout Development Timelines

Canada and the U.S.

1904
First traffic circle

1930's
Traffic circles superseded by rotaries

1950's
No more rotaries

1990's
Roundabouts

United Kingdom

1910
First roundabout

1956
First Yield sign tried

1966
Yield at Entry universal

1970's-80's
TRL tests

1990's
Roundabouts
Roundabouts have been built in the U.K. continuously for over 80 years.

Initially entering traffic had priority.

This meant that to increase capacity the circles had to be large, or they would “lock up”.

Large circles led to entering and circulating traffic weaving in the circulatory road.

Large circles led to high speeds, and less efficient (and more dangerous) weaving.
When Entering Traffic has Priority

You can get in, but you can’t get out!
When There is Weaving

Drivers can enter beside circulating traffic
No Weaving in a Roundabout

Entering drivers yield to circulating traffic
In 1966 traffic regulations were changed in the U.K. so that circulating traffic had priority.

Yield (or Give Way) lines were introduced at the entries.

Traffic could now be stored on the approaches rather than in the circle.

Capacities increased and “lock ups” were eliminated.

However, speeds were still high with the large circles, and even with higher capacities congestion was still a problem.
The Quest for Understanding

- Changes to many of these roundabouts were made to increase capacity
- Entries were widened, and the central islands made smaller
- This resulted in abrupt increases in crashes
- In the late 1970’s a major research program was undertaken to figure out how to increase roundabout capacity without compromising safety
The U.K. Empirical Capacity Model
The Scope of the Research

- Research looked at 86 roundabout entries with a very wide range of geometric variations (conditions that no longer exist today)
- 11,000 minutes of capacity operation were recorded
- 500,000 vehicles were observed
- Geometric parameters that could not be fully investigated in the field were tested at the TRL test track
- A team of 5-6 scientists worked for 10-12 years to complete the research and develop the regression equations
The Scope of the Research
The TRL Test Facility
Initially researchers sought a gap-acceptance model, since it seems intuitive that roundabout entry capacity is determined by the gaps available in circulating traffic.

However, good gap-acceptance models are very complex and require solutions to a number of intermediate problems observed as roundabouts approach capacity.

It takes more work to also relate them to roundabout geometry.
Some Capacity Mechanisms

Geometry

- Gap acceptance
- Driver behaviour types
- Priority reversal
- Lane interaction

Capacity

- Gap forcing
- Interaction between entering and circulating traffic
- Merging
Empirical Models

- Empirical models relate roundabout capacity directly to geometry
- They eliminate the need to study all the capacity mechanisms individually (including some that may not even be discovered yet)
- They are geared towards use by designers
Empirical Models vs. Gap Models

- Gap-acceptance models are inherently complex, but are easy to visualize and can be “built from the ground up” through the use of critical headway and follow-up headway times.
- Empirical models require lots of at-capacity data to develop, unless they are borrowed from elsewhere and calibrated.
ARCADY uses the U.K. empirical model to calculate the capacity of each entry as a function of its geometry and the circulating flow crossing in front of the entry.

Entry capacity is

\[ \text{CAP} = F - fc \times Qc \]

Where:

- \( F \) and \( fc \) are constants derived from the geometry.
- \( Qc \) is the circulating flow past the entry.
Capacity of a Roundabout Entry

Cap = F - fc Qc

Circulating Flow (Qc)

F

Cap

fc

Qc

CAP
According to the U.K. empirical model, the geometric parameters affecting capacity are

- Road half width, $V$
- Entry width, $E$
- Effective flare length, $L'$
- Entry radius, $R$
- Entry angle, $\phi$
- Inscribed circle diameter, $ICD$
Road Half Width, V
Effective Entry Width
Entry Width, E

- Appropriate upper limits for E
  - Single-lane entry = 4.25 m
  - Two-lane entry = 8.0 m
  - Three-lane entry = 12.0 m

- Care is needed with entry width
- For example, if an entry width of 6.0 m is used for a single-lane entry, the U.K. model will assume some degree of two-lane operation
Effective Flare Length, L’
Entry Radius, $R$
Entry Angle, $\varphi$
**R and $\varphi$ are Related**

- **Large $R$, small $\varphi$**
  - High capacity

- **Small $R$, large $\varphi$**
  - Low capacity
Inscribed Circle Diameter, ICD
Revisiting the U.K. Capacity Study

- A follow up study was done in the U.K. in the early 1990’s at 35 roundabouts to verify the results of the original research.
- The study concluded that no changes to the capacity model were necessary.
- The total cost of the capacity and safety research including the follow-up study, in 1998 funds, was $11.5 million – an amount unlikely to be dedicated to roundabout research today.
The U.K. Empirical Safety Model
The major research program undertaken in the U.K. also extended in the early 1980’s to determining relationships between geometric parameters and roundabout safety.
The Scope of the Research

- Research looked at 84 roundabouts with a very wide range of geometric variations (conditions that no longer exist today)
- 1,427 injury collisions at roundabouts were studied
- Over 5 years of collision data were collected at each roundabout
- A team of 5-6 scientists worked for 10-12 years to complete the research and develop the regression equations
Results of U.K. Safety Study

- According to the U.K. empirical safety model, the geometric parameters affecting safety are:
  - Angle between legs, $\theta$
  - Entry width, $E$
  - Road half width, $V$
  - Circulating width, $Cw$
  - Approach curvature, $Ca$
  - Entry path radius, or deflection
Entry Path Radius

Optimum range
A Word of Caution

- The U.K. capacity model can be calibrated for use in other countries.
- However, because of differences in crash reporting methods, the same cannot be said for the U.K. safety model.
- Still, the safety model can be useful for comparing expected safety performance on a relative basis between different roundabout designs.
NCHRP Report 572 and the 2010 HCM
NCHRP Report 572

- Study of roundabout capacity and safety in the U.S. completed in 2007
- 300 minutes of capacity operation were recorded at 14 roundabouts in 2003
- Found that roundabout capacities over-predicted by the various overseas models used for comparison, including both the U.K. empirical model (RODEL) and Australian gap model (SIDRA)
NCHRP Report 572 Results

ME01-E (Gorham, ME)

W04-N (Port O...

MD06-N (Lothian, MD)

WA03-S (Bainbridge Island, WA)

SimCap User Group Event
July 2014
Roundabout capacities were over-predicted by the overseas models because:
- The sample size was small
- U.S. drivers are likely more uncertain or less aggressive at roundabouts
- Some roundabouts had ineffective geometry
- There was very little sustained at-capacity operation

The finding is not surprising, given the current level of roundabout implementation in the U.S.
Will it be the case in the future (i.e. 20 years)?
A model was therefore developed to reflect current conditions at U.S. roundabouts.

Exponential equations were brought forward because they had a slightly higher correlation with available data than linear equations.

The 2010 HCM adopts the NCHRP Report 572 equations.

It also recognizes that they can be supplemented by “alternative tools” (ARCADY, SIDRA, etc.), especially in cases of flared or three-lane entries.
Models and Model Error

SimCap User Group Event
July 2014

- Entering Flow, $Q_e$
- Circulating Flow, $Q_c$
- HCM 2010 Model Error ($\pm \%$)
- U.K. Empirical Model Error ($\pm 15\%$)
Roundabout Capacity Calibration
ARCADY can be calibrated to reflect the lower entry capacities typically seen at roundabouts in the U.S. (and, presumably, Canada)

But how?

Will whatever calibration used initially be appropriate in 20 years?
Linear Regression Fit to Data

Entering vs. Circulating Traffic (vph)
ARCADY Prediction (Default)
Reducing the Capacity

**Entering vs. Circulating Traffic (vph)**

- **Hourly Total**
- **Linear Regression**
- **ARCADY (Default)**
- **ARCADY (67% Capacity)**
Reducing the y-Intercept

![Graph showing entering vs. circulating traffic (vph)](image-url)
As seen with U.S. data, a capacity or y-intercept reduction of 15% may be appropriate for current conditions.

If modelling future traffic flows, by the horizon year somewhat less than a 15% capacity reduction is likely to apply due to increased driver familiarity with roundabouts.

How about:
- 15% for 1-9 years after opening
- 10% for 10-19 years after opening
- 5% for 20+ years after opening
Recommended Analysis Methodology

- Predict capacity, then apply a capacity reduction to each roundabout entry
- Compare results with and without the capacity reduction
- If additional lanes are needed with the capacity reduction, then discuss the design, safety and cost implications so a decision can be made whether to provide the additional capacity
- Perhaps the roundabout design can be staged such that an interim version is constructed initially
Testing for Critical Entries

**Case 1**

Delay

Mean prediction of capacity

More pessimistic prediction of capacity

Range of capacity prediction

V/C Ratio
Testing for Critical Entries

Case 2

Delay

More pessimistic prediction of capacity

Mean prediction of capacity

Difference in delay

V/C Ratio
*** ARCADY Demo ***
The “One Hour” Flow Profile

Demand Flow

Time (mins.)

Peak hour flow

0 15 30 45 60 75 90

SimCap User Group Event
July 2014
Steady-state queuing theory is applicable when traffic demand is well under capacity.
But it predicts infinite queue lengths when the V/C ratio is 1.0 or greater (even when high traffic intensities last only short periods).

Deterministic queuing theory is applicable when traffic demand is well over capacity.
But it assumes a steady arrival rate, so there will be no queuing whatsoever until the V/C ratio exceeds 1.0.
In real life vehicles do not arrive at a steady rate, and there will always be probability of a queue existing even when the V/C ratio is less than 1.0.

“Time-dependent” queuing theory is a transformation that progressively moves from steady-state to deterministic theory.

It accounts for random arrivals and the length of time for which given traffic conditions have existed.

The resulting equations (built into ARCADY) have shown good approximations to the actual build-up of queues at or near capacity.
Time-Dependent Queuing Theory

Queue Length

Steady-state theory

Transformed curve

Deterministic theory

V/C Ratio

1.0
Lane-By-Lane Modelling
• ARCADY assumes that entering traffic is distributed evenly across the available lanes regardless of actual demand or lane configuration
• If there are exclusive left- or right-turn lanes then actual delays may be higher and capacity should be evaluated on a lane-by-lane basis
• Systematic incomplete lane use will also require a lane-by-lane analysis
For a lane-by-lane analysis on a 2-lane entry, adjust the capacity (slope) by 50%.

On a 3-lane entry adjust by 67% for 2 lanes or 33% for 1 lane.

When assessing one lane, insert 000 as the volume for the other lane(s) to eliminate that volume from the assessment.

Check each lane individually to see if an alternative lane configuration is needed.
The U.K. empirical model was developed from data that included a variety of lane configurations at the roundabouts studied. However, if there is significant unequal lane usage, then ARCADY also has an Entry Lane Analysis Mode to compare the relative performance of different lane configurations. It is an analytical model that uses a simulation technique rather than one developed from empirical studies, and so judgment is needed in reviewing the results.
Wrapping Up
What Else Can ARCADY Do?

- ARCADY can model mini-roundabouts, linked roundabout networks, grade-separated roundabouts, and pedestrian crossings (unsignalized or signalized) at roundabouts.
- It can be linked to AutoTRACK (now Autodesk Vehicle Tracking) which allows the geometry to be done in CAD and then as the geometry is modified the ARCADY analysis is updated automatically.
What Versions Are There of ARCADY?

- The latest version is ARCADY 8
- ARCADY Lite, with a simpler front end, was introduced in March 2014 for the U.S. and Canadian markets
- You can start with ARCADY Lite and upgrade to ARCADY Full at a later stage
- ARCADY’s sister product is TRANSYT 15 for network modelling, which if you have a license for ARCADY allows you to mix and analyze networks of signals and roundabouts
How Can I Purchase ARCADY?

- Go to the TRL Software website
- You can download a free demo version that allows input but does not provide any output
- You can also request a free trial version that is fully-functional but will time out after a set period of months
- The trial version is good for workshops and training sessions
- The TRL continues to invest heavily both in research and development of ARCADY and other software
Thank You

Questions?

TRL