HCM Roundabout Capacity Methods and Alternative Capacity Models

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ABSTRACT

Traffic analysts and designers are anticipating the new Highway Capacity Manual 2010 (HCM 2010) capacity formulae for single-lane and two-lane roundabouts. The new HCM 2010 will acknowledge roundabout capacity analysis models from other countries, but will caution on their use without calibration to U.S. conditions.

These new U.S. roundabout capacity formulae are being introduced based on research from National Cooperative Highway Research Program (NCHRP) Report 572, published in 2007. The capacity of a roundabout entry (Q_e) was found to be a function of one flow variable, circulating flow (Q_c), in a negative exponential regression equation. This differs from research in the United Kingdom, for example, which revealed a linear relationship with substantive geometric sensitivity (Kimber, R.M., *The Traffic Capacity of Roundabouts*, TRRL Laboratory Report 942, 1980).

There is an expectation of the new HCM formulae being capable of providing accurate predictions of roundabout entry capacity. Even so, without geometric sensitivity other than number of lanes, analysts and designers will not have all the tools necessary to develop robust roundabout designs capable of accommodating high-than-expected traffic demand or differing driver behavior from one location to another. Since geometric variation is not expected in the new HCM 2010 capacity procedure, this paper reviews alternative techniques to adapt the U.K. empirical model to the design implications of the recent U.S. data.

Two alternative adaptation methods are contrasted and evaluated to demonstrate their correlation with recent U.S. practice, research and observations of built roundabouts. Neither one provides an ideal method of calibrating to the 2010 HCM. One method, of equating the y-intercepts of the U.K. and HCM equations, makes no progress in the goal to recognize geometric sensitivity while using the U.S. roundabout capacity data. The other method holds interest but requires a more complicated adjustment technique.

INTRODUCTION

The HCM 2000 documents a procedure for estimating the capacity performance of each leg of a single lane roundabout based on the conflicting circulating flow and two gap acceptance parameters: critical gap and follow-up time (1). The HCM 2000 procedure for roundabouts had value as a planning tool to approximate single lane entry capacities until more recent research provided a new empirical capacity equation (2). However, at high levels of conflicting flow other capacity mechanisms occur and a simplified gap acceptance model may not give reliable results.
At high demand when a roundabout entry becomes saturated, other capacity mechanisms have been shown to occur such as: circulating traffic adjusting headways to allow vehicles to enter; and priority reversal, where entering traffic forces circulating traffic to yield (2). These capacity mechanisms can only be accounted for by collecting data on the traffic streams directly and over the whole range of circulating flows (3). Where this has been done for at-capacity saturated roundabout entries the results have been reliable, with between-site variations of +/-15%.

Intersection analysis models generally fall into two categories: empirical and analytical. Analytical models are based on the concept of gap acceptance. Empirical models, generated from field data, can introduce direct capacity relationships between capacity and geometry. Designers tend to favor empirical models based on the ability to assess the effects of geometric design changes on operational performance. Empirical models are therefore more useful but require substantial data collection from saturated roundabout entries to generate reliable results. The choice of model also depends on the calibration data available.

Agencies are seeking direction on methods to reconcile the U.S. data to alternative models that have been in use by U.S. engineers for over a decade. Recognizing the US model is incomplete and still needs work; agencies are asking how to advance with older proven tools while benefiting from the recent US data. Concurrently they are seeking methods that are transparent and uniform. This paper focuses only on the U.K. empirical model and its adaptability for comparison with the HCM 2010 roundabout equations.

**NCHRP 3-65 RESEARCH AND PROPOSED HCM CAPACITY METHOD**

Based on recent analysis of U.S. field data simple, lane-based, empirical regression models are recommended by Transportation Research Board for both single-lane and two-lane roundabouts (2). The capacity model is based on one-minute observations of continuous queuing on a roundabout entry. The single-lane model is given by:

\[ c = 1130 \cdot \exp(-0.0010 \cdot v_c) \]  

[Equation 4-4]

Where:
- \( c = q_{e,max} \) = entry capacity (veh/h)
- \( v_c = q_c \) = conflicting circulating traffic (pcu/h)

Despite the way roundabouts operate, the performance of one leg is analyzed independently of another, thus other analysis models and techniques are required to account for the variation in capacity of an entry over a peak hour and its varied effect on delay and queuing. This is an area of interest where empirical models can provide improved predictions.

The capacity equation for a single-lane roundabout given above was derived from observations of a relatively small sample of U.S. roundabouts in 2003 (2). It is expected
that capacity at U.S. roundabouts will increase over time with increased driver familiarity. Likewise, regions having more roundabouts built over time may already be experiencing higher capacities at these roundabouts.

The multi-lane model was developed for the critical lane of a two-lane entry. There were few instances in the field data collection effort whereby a steady-state queue existed on all lanes of a two-lane entry. Most commonly, for the two-lane entries, the collected data revealed the outside lanes had sustained queues while the inside lanes only had sporadic queuing. The capacity of the non-critical lane is the same as the critical lane if the length of this lane is assumed to be unlimited. The results from NCHRP 3-65 study yielded the following capacity relationship (2) for the critical lane of a multi-lane entry:

$$c_{\text{crit}} = 1130 \cdot \exp(-0.0007 \cdot v_c)$$  
[Equation 4-7]

Where:
- $c_{\text{crit}} = q_{e,\text{max,crit}}$ = capacity of the critical lane (pcu/h)
- $v_c = q_c$ = conflicting flow (pcu/h)

The multi-lane capacity empirical regression model can be calibrated using local data for the critical gap and follow-up headway parameter.

**Delay, Queues, and Level of Service (LOS)**

Control delay and 95th percentile queue estimates for the peak 15 minute traffic volumes are obtained from delay equations given in the HCM 2000 stop control capacity procedure, Exhibits 17-19 and 17-20 (2) but without the extra 5 seconds that accounts for the difference between stop control delay and yield control delay. At high entry demands, the 5 extra seconds of delay that accounts for stops at the entry to a congested roundabout might be kept in the equation. The HCM 2000 LOS criteria stated previously, with thresholds the same as unsignalized intersections, is likely to be adopted in the 2010 HCM because of the similarity in the gap seeking characteristics between unsignalized conditions and yield control.

**PROPOSED HCM 2010 CAPACITY PROCEDURE – A LOW-DEFINITION MODEL**

Modern roundabouts are relatively new to the U.S., with most sites being less than 10 years old and very few that have experienced design year demands. Without continuous congestion that generates saturated entries, a robust set of at-capacity observations is not yet achievable. This dilemma is acutely evident because the multi-lane model is capable of predicting capacities for only one lane of a two-lane entry. While the proposed HCM 2010 procedure represents the best available data on U.S. roundabouts to date it will be several more years before enough roundabouts reach saturated conditions to foster an update to the current model.
In the next iteration of capacity research, development of predictive variables accounting for second order geometric design effects on entry capacity is a must. Geometric sensitivity has proven to be an integral part of capacity prediction in other jurisdictions but is somewhat elusive in the U.S. mainly for reasons mentioned above, along with the fact that a more extensive research effort is required to cover both saturated entries and a wider range of geometric designs.

With the low number of U.S. roundabouts currently operating with high delays, prediction of higher magnitudes of delays for longer time periods, e.g. greater than 15 minutes, requires a more robust approach. If the degree of saturation for a roundabout entry is greater than 0.9, for the recommended analysis period of 15-minutes, results calculated by the procedure may not be accurate due to antecedent queues at the start of the time period. Earlier U.K. research into this condition yielded an iterative approach that accounts for the spillover effects of queues from one time period to the next (4).

There are inherent weaknesses in choosing a negative exponential equation to define capacity of a roundabout entry, particularly one that is gap-acceptance based. Figure 1 illustrates the two equations and the area of weakest interpolation of their regression, where circulating flow is highest. The equation becomes nearly asymptotic to the x-axis making it unreliable to model the reality that very little traffic can enter a roundabout when circulating traffic volume is excessive.

If the proposed 2010 HCM accommodates the use of alternative empirical models that contain high-definition geometric sensitivity in addition to the number of lanes, then calibration of alternative models is essential to the preservation of empirically-based design.

**A HIGH-DEFINITION EMPIRICAL MODEL**

Over a period of about 12 years the U.K. government established robust, dependable relationships for the capacity of roundabouts (3)(4). The whole purpose of the research program was to produce a model that a traffic engineer could use to design roundabouts that would thoroughly satisfy the intersection’s operational requirements. The intent was to produce equations that give practical links between geometry and capacity, delay and queuing.

The size of the databases for capacity studies speak for themselves:

- 86 roundabout entries studied
- 11,000 minutes of capacity operation recorded
- 500,000 vehicles observed

The outcome of the linear regression analysis of a substantial collection of at-capacity traffic streams was that there were only 6 significant geometric parameters that played a role in determining capacity. They were entry width \((e)\), approach width \((v)\), flare length \((\ell, \ell' - \text{the length over which local widening of the approach is developed})\), entry angle
incribed circle diameter (D) and the radius of the curb at entry (r). All other parameters proved insignificant. This led to comparatively simple relationships which have proved remarkably robust. The best predictive equation for entering capacity $Q_e$ was found to be:

$$Q_e = F - f_c Q_c$$

Where $F$ and $f_c$ are positive constants determined by the equations listed in Appendix A.

It has often been said that the U.K. relationships are only valid in the U.K. and only for U.K. drivers. There is some truth in this since the relationships were developed using exclusively U.K. data. Although there may be some deviations from U.K. values, and not always the same deviations from one country to another, it is extremely unlikely that a change which improves capacity in the U.K. is going to have the reverse effect in another country. Detailed results may vary, but this criticism applies at least equally to gap acceptance methods calibrated in the U.S.

**Design Implications of a Geometrically-sensitive Empirical Model**

An important product of establishing an empirical model that is sensitive to geometry is that designers can straightforwardly fine-tune numerous parameters in order to achieve a reasonable balance between capacity, safety, and cost. Without the capability to predict different capacities for a variety of configurations or number-of-lane-based designs, the designer runs the risks of overdesigning, decreasing safety, and increasing cost. Consequently, geometrically-sensitive design methods are sought after by clients, agencies, and owners to achieve required capacity targets while minimizing right-of-way impacts, avoiding high construction costs, and balancing the safety of all users.

**ADAPTATION OF ROUNDABOUT CAPACITY MODELS TO U.S. DATA**

While the foregoing procedure represents the ideal approach to localizing the empirical design model in the U.S. it poses several short-term challenges. Other methods of calibration, however formal, mathematically crude or approximate, are worthy of discussion in this early process of adapting alternative models to the recent U.S. research. Given the weight of the proposed 2010 HCM roundabout capacity procedure on the roundabout engineering community, the proposed model may be seen, for better or worse, as the benchmark against which other models will be tested.

Based on the NCHRP Report 572 findings of the evaluation of existing international models, calibration to U.S. conditions appears necessary, at least in the short term, to improve the quality of capacity estimates. In consideration of the need to adapt alternative models to the proposed HCM model, it is fitting to develop, discuss and evaluate alternatives on some rational basis. The possible criteria for development of an adaptation procedure for the proposed HCM 2010 roundabout capacity model and for future calibration are:
• Adaptability to the varying driving environments e.g. urban versus rural;
• Roundabouts with more than two entering lanes can be modeled;
• Capacity mechanisms that only appear for saturated conditions over multiple time periods, e.g. over 20-minutes are accounted for;
• That it can be applied uniformly within a road agency, simply and traceably;
• Capacity trends associated with geometric design sensitivity are retained; and,
• Field-collection techniques are not complex, i.e. data collection is simple and reproducible, e.g. collection of gap parameters vs. collection of minute-by-minute entry and circulating flows.

Whatever procedure is chosen, it must be adaptable to the ideal calibration procedure, outlined in Appendix B, which employs a robust geometrically sensitive model ultimately for U.S. roundabouts. This should be the ultimate goal of any research into capacity parameters associated with roundabouts. Producing anything less blinds the sensitivity of the designer to subtle changes in geometry that make designs robust and at the same time context sensitive.

Model Adaptation Alternatives

As a demonstration exercise the U.K. model was adapted to the proposed HCM 2010 roundabout equations without losing all of geometric sensitivity that the model provides. If this can be done effectively and uniformly, the U.K. model can continue to be used to predict the capacity effects of discrete geometric design changes on U.S. roundabout designs with greater confidence in the local results.

The key parameter in the U.K. equation for capacity is the y-intercept (F). It contains the major capacity influences of entry width, flare length and approach width. If the y-intercept can be adjusted, then the slope of the linear equation, that also contains the major capacity geometry relationships, can be preserved using the adapted U.K. model. Therefore, geometric sensitivity can be promoted with consideration for U.S. conditions.

Among the possible alternative methods of adapting alternative models to the proposed HCM 2010 roundabout equations, four that make use of the U.K. empirical model are examined and compared for their complexity, advantages and disadvantages, namely:

1. Calibration of gap parameters of NCHRP Report 572 model
2. Adjustment of U.K. equation (Y-intercept (F) = 1130, (NCHRP Report 572)
3. Curve-fitting method (U.K. Equation to Proposed HCM 2010 Equation)
4. Employ the U.K. method of developing the y-intercept adjustment

1. Calibration using gap parameters of NCHRP Report 572 model

Future local calibration of the proposed HCM 2010 capacity model was anticipated to reflect site and traffic variations. Variables can be estimated by field measurement using the single lane and multilane expressions yielding a simple method of calibration:
\[ q_{e,\text{max}} = A \cdot \exp(-B \cdot q_c) \]  

[Equation 4-7]

Where:

- \( A = \frac{3600}{t_f} \)
- \( B = \frac{(t_c - t_f/2)}{3600} \)
- \( t_c = \text{critical headway (s)} \)
- \( t_f = \text{follow-up headway (s)} \)

Advantages

This model is able to calibrate the NCHRP 572 equations by using only one other site’s gap parameter data, providing it is a similar driving environment (e.g. both sites are low-speed urban locations) and that the other site is genuinely congested. It also appeals to analysts familiar with stop-controlled intersections in that it uses familiar data collection and capacity techniques. Lastly, the gap parameter adjustment procedure is straightforward and is outlined in the draft chapter of the proposed 2010 HCM (2).

Disadvantages

An effort to adjust gap parameters has several inherent assumptions which are cause for question when applied to roundabout capacity analysis. Geometric parameters are irrelevant and steady-state flow does not exist. It is more difficult to collected gap data than direct measurement of entry-circulating flows; and, the results provide no direction as to what geometry would be most effective – a key concern for designers. Ultimately, use of gap parameters continue to use the negative exponential equations which have no x-intercept i.e. the model is clearly very weak at predicting entry capacity when circulating flows are high (see Figure 1).

Although the ability to calibrate the gap-acceptance model proposed for the 2010 HCM is appealing due to the familiarity of gap parameters, this method is not viewed by the authors as a desirable long-term procedure for assessing, laying-out or modifying roundabouts in-service.

The y-intercept value of 1130 was derived from the regression best fit of U.S. capacity data. As more research is gathered and as more roundabouts reach capacity, this figure is expected to rise. If the average follow-up headway were to decrease from 3.2 seconds to 2.8 seconds, the intercept would be 1285. Values for follow-up time as low as 2.6 were recorded in the NCHRP 3-65 study. Intercept values of 1400 are not unreasonable for well-designed single lane roundabouts. Applying the current low value will result in overdesign as many roundabout schemes will require a second lane when the model reports over-capacity results for values exceeding an intercept of 1130.
2. Equating the U.K. equation Y-intercept (F) to the NCHRP Report 572 intercept 1130

NCHRP reported a large improvement in the RMSE when the y-intercept of the UK model is calibrated. The U.K. model equation contains a constant associated with the y-intercept (F) of the linear regression equation (see Appendix A). The constant of 303 indicated in the y-intercept of the entry capacity equation is then adjusted to adapt the U.K. linear equation to the proposed HCM 2010 equations for single lane and critical lane of a two lane entry. Accordingly, the y-intercept, F, is equated to the intercept of the proposed HCM 2010 equation, 1130.

Given that the measured entry capacity and conflicting flow is known, the expression for the y-intercept can be rearranged to estimate the local value of this constant. The revised localized intercepts can be developed over a range of geometric design and capacity combinations for single lane and multi-lane roundabouts. Figures 2 and 3 illustrate the adaptation of the U.K. equations for a compact and low-capacity geometry, and also a high-capacity geometry for both 1-lane and 2-lane entries for the values in Table 1. Figure 3 illustrates the critical lane of a 2-lane entry.

When the y-intercept of 1130 is used and the slopes of the linear equations relating to specific geometry are preserved, Figures 2 and 3 shows the superposition of the capacity equations onto the y-intercept of 1130. Surprisingly, the low capacity roundabout becomes the higher capacity equation and the high capacity roundabout trades places. This is because the slope of the linear equation that contains the inherent geometries is being preserved.

For the critical lane of a two lane entry, the slope of the U.K. equation is halved to obtain a form suitable for use as the critical lane in conjunction with the HCM 2010 equation. When the linear equations are super-positioned the effect is similar to the single lane case, where the two designs trade places in terms of capacity predictability.

<table>
<thead>
<tr>
<th>Geometric Parameter</th>
<th>1-lane Entries</th>
<th>2-lane Entries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>e (m)</td>
<td>3.50</td>
<td>4.25</td>
</tr>
<tr>
<td>v (m)</td>
<td>3.00</td>
<td>3.75</td>
</tr>
<tr>
<td>ℓ' (m)</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>D (m)</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>φ (°)</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>r (m)</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>F (y-intercept)</td>
<td>972</td>
<td>1345</td>
</tr>
</tbody>
</table>

* Critical lane of a 2-lane entry.

The slope and intercept for a short lane flare will require a separate calculation not covered in this review.
Advantages

The apparent benefit of the local variable method is that it retains geometric sensitivity. Given that several agencies currently apply the UK model in their capacity analyses, modifying the local variable allows easy adaptation to the HCM models. For designers, this method enables adaptation of large sets of roundabout geometries or individual layouts. Adjusting the local variable such that the y-intercept is equal to the NCHRP 572 equation prediction unifies the method of adjusting the U.K. model.

Disadvantages

A fatal flaw in this adjustment method is readily apparent from Figure 2 whereby preserving the slope results in unreasonable capacity predictability of the low and high designs being reversed. Equating the y-intercepts assumes that the NCHRP capacity equations are robust for most roundabouts, but the results appear to be unreasonably conservative except at the y-intercept.

The local variable method is shortsighted in that it does not improve the accuracy of the proposed 2010 HCM model. It would be better to use the original linear equations as shown typically on Figures 2 and 3 then make more subtle adjustments to the intercept without creating unreasonably low expectations of capacity, particularly at higher circulating flows. A basic adjustment of 10 to 15-percent to the y-intercept or performing a sensitivity analysis to identify the volume threshold where the geometry becomes weak would be preferred over blindly equating the U.K. linear equation intercept to 1130.

3. Curve-fitting method (U.K. Equation to Proposed HCM 2010 Equation)

An alternative method of shifting the y-intercept of the U.K. model towards the eventual HCM standard is to simply calculate the best fit of the linear equation to the exponential curve while maintaining the slope of the U.K. linear equation. This can be accomplished by several methods including using the linear least squares method. Again, the exponential equation approaches the x-axis asymptotically at the higher ranges of circulating flow, which is unrealistic in either model. The right-hand limit of the curve-fitting can be reasonably set to the x-intercept of the linear equation.

In the equation below, the x-intercept, Q_x, can be solved iteratively, where \( f_c' \) represents the slope of the U.K. capacity equation in terms of the critical lane, C is the constant in the exponent of the NCHRP equations, and k is a constant of the U.K. model. The F-value or y-intercept is also derived from this method of curve fitting. Thus the slope of the equation is preserved and the intercept is adjusted to more closely approximate the HCM exponential equation

\[
\frac{2260(1 - e^{-cQ_x})}{Ck f_c' Q_x^2} = 1 \quad [\text{Equation 3-1}]
\]
Figures 4 and 5 show preliminary results of this method based on 4 of the roundabouts included in NCHRP Report 572. The results may be finalized once the raw data requested from the NCHRP study team becomes available.

**Advantages**

The curve-fitting method is easy, quick, and practical. In addition to retaining geometric sensitivity (by essentially adjusting the local variable), it is naturally the best fit of a linear equation to the existing exponential model. At low and high flows it expresses conservative results relative to NCHRP. Equation 3-1 is versatile in that it is applicable to 1-lane and 2-lane entries, can average large sets of roundabout geometries, and is still valid if the gap parameters are adjusted as outlined by NCHRP Report 572 (2).

**Disadvantages**

A large data set of roundabout geometries is needed if an accurate global average slope is desired. The method is relatively complicated and requires a brief iteration to establish boundary values. The curve-fitting model is shortsighted in that it doesn't improve the accuracy of the proposed 2010 HCM equations.

4. **UK calibration method**

Along with the results of the U.K. research (3), a procedure was developed to continuously improve the quality of capacity predictions and, importantly, to correct the capacity formula for local conditions. This is possible only if the relevant entry is substantially overloaded during peak periods. A full explanation of this method is outlined in Appendix B.

**Advantages**

This method can be called calibration because it uses a data collection method identical to the original research will yield the most accurate site-specific calibration results. The model can be applied to multilane roundabouts without needing to consider the critical lane. This method is especially useful for assessing an in-service roundabout that has one or more oversaturated entries.

The paradox of using U.K. capacity equation is that a roundabout with seemingly hopeless congestion can be improved with subtle changes to geometry that doesn’t have to include adding lanes. This method has been in use for over twenty years improving badly congested roundabouts where space and constraints would preclude adding lanes.

The method is also practical for future development of a U.S. capacity model based on geometric sensitivity. If enough sites with varied geometry and traffic characteristics can be assessed, a growing database of capacity studies will allow the adoption of the U.K. model over time.
Disadvantages

The cost of assembling enough data to fully utilize the U.K. model is high and nearly impossible at this time without enough congested roundabouts. Currently, individual sites can be assessed and the model utilized to make geometric improvements if the candidate site has one or more saturated entries. The model could be calibrated from one site for application to another site but only if the candidate site has a similar driving environment, e.g. urban versus rural and similar geometry.

CONCLUSION

This review of is an invitation to maintain interest in a historically robust empirical model. The recent U.S. research and data was unable to identify geometric variation with capacity for effects below the number of lanes. The HCM 2010 roundabout capacity equations provide a guideline to compare the more robust U.K. model over a range of geometric variation; however, the proposed HCM 2010 model is a low-definition model by comparison to the design capability of the U.K. model.

Standing in the way of using the U.K. model is a shortage of sites from which to sample at-capacity data. In time, the geometry-capacity relationships of roundabouts will be revealed when a thorough and persistent effort is applied. Designers who have had a taste of empirical, geometrically-sensitive models refuse to accept an inferior approach. Independent studies are underway to collect the baseline data.

The U.K. model and the related procedure for calibrating it to local conditions are feasible for U.S. roundabouts when sites that experience design year flows are more numerous. In the meantime, local calibration to sites with similar geometry and traffic characteristics, e.g. urban versus rural, is possible where a comparable control study sites exist with saturated entries for periods longer than 20 minutes.

Two alternative methods of adapting the U.K. model to U.S. data were evaluated and documented. One focuses on the y-intercept of the HCM 2010 negative exponential equation (1130) in order to adjust the alternative models without altering the slope of the U.K. equation. That method equates y-intercepts then adjusts the U.K. equation to maintain its linear slope so that geometric sensitivity is retained when using the U.K. model in the U.S. This method is shortsighted in that it does not improve the accuracy of the proposed 2010 HCM model.

Past design practice has shown that using the original linear equations is preferred with more subtle adjustments to the intercept without creating unreasonably low expectations of capacity, particularly at higher circulating flows. This can be done by performing sensitivity capacity tests using increasingly higher traffic flows to examine where the delay versus volume to capacity ratio produces unstable delay and excessive queues. Geometry is then adjusted to increase the confidence in the design for the design year flows. A basic adjustment of 10% or 15% to the y-intercept, combined with
a sensitivity analysis, can identify the volume threshold where the geometry becomes weak. This is preferred over blindly equating the U.K. equation y-intercept to 1130.

A second technique adapts the U.K. equation to the U.S. data by approximating the proposed 2010 HCM equation through a mathematical curve fitting technique. This method is more sophisticated, but it can address a wide range of geometries for closer comparison to the proposed 2010 HCM equations. The method of curve fitting warrants further interest and possible development into practice concurrent with the proposed 2010 HCM roundabout procedure.

The ideal approach for adapting the U.K. model to the U.S. data will continue to be to collect more data from saturated roundabout entries and to adjust the slope and intercept according to the U.K. calibration procedure. This benchmark calibration method should be sought after vigorously as the proposed 2010 HCM roundabout capacity procedure is unveiled.
FIGURES AND TABLES

Figure 1 - Roundabout entry capacity for single-lane entries and critical lane roundabout entry capacity (Source: NCHRP Web-Only Document 94: Appendixes to NCHRP Report 572: Roundabouts in the United States)

Figure 2 – Equating the U.K. equation Y-intercept (F) to the NCHRP Report 572 intercept 1130
**Figure 3** - Equating the U.K. equation Y-intercept (F) to the NCHRP Report 572 intercept 1130 Critical Lane of Two Lane Roundabouts

**Figure 4** - Curve-fitting method (U.K. Equation to Proposed HCM 2010 Equation) Single Lane Roundabout
Figure 5 - Curve-fitting method (U.K. Equation to Proposed HCM 2010 Equation)
Two Lane Roundabout
APPENDIX A

Empirical Regression Capacity Equation for Roundabouts

\[ Q_e = F - f_c Q_c \]

Where \( Q_e \) is the entry flow or capacity; \( Q_c \) is the circulating flow in pcu/h; \( F \), the y-intercept, and \( f_c \) the slope of the linear regression, are positive constants determined by the equations listed below:

\[
k = 1 - 0.00347(\phi - 30) - 0.978\left(\frac{1}{\ell} - 0.05\right)
\]

\[ F = 303x_2 \]

\[ f_c = 0.210t_D(1 + 0.2x_2) \]

\[ t_D = 1 + 0.5/(1 + \exp((D - 60)/10)) \]

\[ x_2 = v + (e - v)/(1 + 2S) \]

\[ S = (e - v)/\ell = 1.6(e - v)/\ell' \]

Where \( e \), \( v \), \( \ell \), \( \ell' \), \( D \), and \( r \) are in meters, \( \phi \) in degrees, and \( Q_e \) and \( Q_c \) in pcu/h. The ranges of the geometric parameters in the data base were:

- \( e: \) 3.6 – 16.5 (m)
- \( v: \) 1.9 – 12.5 (m)
- \( \ell, \ell': \) 1 – ∞ (m)
- \( S: \) 0 – 2.9 (m/m)
- \( D: \) 13.5 – 171.6 (m)
- \( \phi: \) 0 – 77°
- \( r: \) 3.4 – ∞ (m)

The primary elements of design are \( e \) and \( \ell \) (or \( \ell' \)).
APPENDIX B
CORRECTION FOR LOCAL CONDITIONS AT EXISTING SITES (3)

(i) Make on-site counts of the total inflow from the entry and the corresponding circulating flow across the entry during successive minutes during which there is continuous queuing in all available lanes in the approach to the entry. Queuing should occur continuously for periods of twenty minutes or more during peak periods. The approach queues should be stable for at least five vehicle lengths upstream of any entry widening. At minimum a total of sixty minutes of saturation should be obtained.

(ii) Calculate the mean entry flow $\bar{Q}_e$ and mean circulating flow $\bar{Q}_c$ for all of the saturated minutes together, both in pcu/h.

(iii) Calculate from the roundabout geometry the slope of the entry/circulating flow relationship by means of equation (a):

$$f_c = k(0.210\tan(1+0.2x_2))$$

(Where: $k = 1 - 0.00347(\phi - 30) - 0.978\left(\frac{1}{r} - 0.05\right)$).

(iv) Then the locally corrected y-intercept is given by:

$$F' = \bar{Q}_e + f_c \bar{Q}_c,$$

and the entry/circulating flow line is thus:

$$Q_e' = F' - f_c Q_c.$$

The confidence limits associated with equations obtained in this way depend on the conditions of operation of the entry in question, but typically the standard error of estimate near the mean will be less than 100 pcu/h. It can be evaluated for any given site simply by calculating the standard deviation, $\sigma$ (pcu/h), of the one-minute counts of $Q_e$, and the correlation coefficient, $R$, between the $Q_e$ and $Q_c$ values. Then the standard error of the predicted capacity near the mean will be: $\frac{\sigma \sqrt{(1 - R^2)}}{N}$, where $N$ is the number of one-minute counts. Both $\sigma$ and $R$ depend on the conditions of operation, and are thus site-specific.
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