CALIBRATION OF CAPACITY PARAMETERS FOR SIGNALIZED INTERSECTIONS IN INDIANA

By

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ABSTRACT

Past research has indicated that the accuracy of traffic quality studies strongly depends on capacity parameters, particularly when demand approaches capacity. Minimal work has been done in the past on local values of the base saturation flow rate and lost times used in capacity analysis of signalized intersections. This paper discusses saturation flow studies conducted for Indiana.

The results confirm that the default parameters recommended by the Highway Capacity Manual, such as the heavy vehicle equivalency factor and the protected-left turn adjustment factor, are adequate for Indiana. At the same time, the base saturation flow rate was found to vary strongly across locations, even when the geometry and traffic conditions were nearly identical, indicating that there are other factors not included yet in the Highway Capacity Manual.

Regression analysis of the saturation flow rate variability identified the size of town to be a good predictor. A model was developed and a set of base saturation flow rates were proposed, which depend on the number of lanes and the town population. The estimated impact of the size of the town estimated for Indiana is very close to the values obtained in the past for other states. The paper provides a convincing argument for adding to the Highway Capacity Manual a population adjustment factor for saturation flow rates.

Keywords: saturation flow rate, capacity prediction, signalized intersections

1. INTRODUCTION

Signal control is a frequently used remedy of capacity shortage in urban areas. Sufficiently accurate methods of predicting the capacity of signalized intersections are important for correct roadway design and for effective traffic management. The Highway Capacity Manual (HCM) (1) provides such a method, together with default values for the key method parameters. These parameters include the base saturation flow rate, lost times, and PHF that have been proven to be important inputs to calculations. The HCM advises its users that “these characteristics at specific locations will vary somewhat from national averages because of unique features” and recommends “that local data collection be performed to determine saturation flow rates and lost times, which
can lead to more accurate computations.” Since determining these parameter values at designed or considerably re-designed intersections is not possible, the HCM default values are often used.

The objective of the presented research is to estimate the Indiana base saturation flow rates and lost times and identify the local factors of the two parameters. Some of the factors considered include the community size, the number of lanes, and the road class. An attempt will be made to develop a method for selecting appropriate capacity parameters values, adequate for local conditions. The goal of the presented research is to improve the accuracy of predicting capacity and performance of signalized intersections in Indiana and other states.

2. BACKGROUND

The HCM specifies the factors of saturation flow rate, including lane width, parking activity, vehicle type, bus stops, approach grade, and others. Selected relevant past studies on capacity factors that include capacity parameters will be discussed shortly. Bonneson and Messer (2) found that the saturation flow rate is significantly higher under traffic pressure, as quantified by high traffic volume per cycle per lane. Studies conducted in Florida (3), investigated base saturation flow rates and lost times in four area types: recreational, residential, business, and commercial. The research indicated that the recreational area had saturation flow rates eight percent lower than the other areas. The same authors concluded in another research that non-local drivers had significant impacts on saturation flow rates and capacity (4). These findings may be considered important where tourism is a major economic activity and effective traffic management is needed to maintain the area’s attractiveness. Zegeer (5) investigated the factors of capacity on several intersections in Kentucky. The author concluded that the saturation flow rate for the same conditions in different-sized communities varied significantly within a range of 83-100 percent with high values in large urban areas.

The inaccuracies of saturation flow rates and lost times caused by not incorporating local conditions may carry over to the delay and LOS predictions. Tarko and Tracz (6) found that inaccurate saturation flow rate estimation may have a strong impact on LOS predictions. They stated that “…this finding indicates an obvious need for frequent updates of predictive formulas for saturation flows and for a careful consideration of local conditions.”
The HCS users’ survey performed by Tarko and Songchitruksa (7) indicates that many professionals have doubts about the results produced by the HCM. The chapter on signalized intersections was frequently pointed by HCM users as provoking a lack of trust in the results, indicating that the results are sometimes unrealistic. Some of the respondents believe that the inputs are not accurate while equations to calculate delays are too sensitive to these inputs and they amplify the inaccuracies.

Khatib and Kyte (8) investigated the sources of errors and their impacts on the level of service prediction. The findings showed that errors in the input parameters were responsible for significant bias in the results when the analyzed intersections operated at high delays. They also recommended the use of site-specific data, if available.

Dowling (9) did a comprehensive study of the effect of using default instead of measured values. He found that using the local values of the PHF, saturation flow rate, and signal progression factor considerably reduced the errors in the delay estimates when the traffic stream was stronger than 85 percent of capacity.

The past research indicates that base saturation flow rates and lost times vary across areas and regions. These differences may be partly caused by different driving behavior, as indicated for Florida and Kentucky, and partly by typically higher volumes in large towns, as indicated by Bonneson and Messer (2). The discrepancy between the assumed capacity parameters in calculations and the actual ones may cause incorrect delay and LOS predictions, particularly when the traffic volumes approach or exceed capacity.

3. METHODOLOGY

The research on the Indiana local factors of capacity parameters included three phases:

1. Data collection,
2. Estimation of capacity parameters, and
3. Variability analysis.
In the first phase, data was collected at selected intersections to facilitate estimation of the saturation flow rate and lost times. Saturation flow rate cannot be measured directly and must be estimated based on the number of discharging vehicles and the time needed for the discharge. The two most popular techniques for counting vehicles and measuring times are direct at the intersections and indirect from a video image. A full motion video recording reduces the risk of error, enables checking, and documents special conditions such as a queue discharge obstructed by a pedestrian or a disabled vehicle. If such events happen very infrequently, removing them from the sample improves estimation accuracy based on a limited number of observations. We decided to use the video-base measuring technique.

The second phase, saturation flow rates and lost times are estimated from the vehicle counts and the time measurements. There are three methods for estimating the capacity parameters.

1. **Headway Method** (Greenshields et al. (10); TRB (1)) estimates the average time headway between the vehicles discharging from a queue as they pass the stop-line. The first several vehicles are skipped to avoid the effect of vehicle inertia in the initial seconds of the green time. The saturation flow rate is calculated as a reciprocal of the mean headway.

2. **TRL Method** (TRRL (11)) counts the vehicles in three saturated green intervals. The saturation flow is calculated as the number of vehicles in the middle interval divided by the length of this interval.

3. **Regression Method** (Branston and Gipps (12); Kimber et al. (13); Stokes et al. (14)) develops an equation involving the saturated green time, the number of vehicles in various categories, and the lost time. In another version, the saturated headways of various vehicle categories and lost time are obtained. The results can be used to estimate the passenger car equivalents for vehicles other than passenger cars.

The headway method was adopted by the HCM and was also used in our studies to preserve the consistency of our estimations with the HCM concepts. Lanes without trucks were analyzed using the headway method. A single modification was required, though, to account for the limited presence of heavy vehicles in some of the studied lanes. We used the regression method to
estimate the saturation headways of passenger cars and of heavy vehicles in the second counting period (after the fourth vehicle’s passage time). Equation 1 in Chapter 5 illustrates use of the regression method applied to the saturated portion of the queue. The estimated regression parameters represent the respective saturation headway for each vehicle type. When the method is applied to the entire queue, an intercept is added to account for the start-up lost time. The simplified regression method does not yield the lost times. These have been estimated using the headway method.

In the third phase, the estimated saturation flow rates and lost times were analyzed using the regression method to identify local characteristics responsible for the site-to-site variability in the capacity parameter values. Considerable variability caused by the imperfect measurement was accounted for with weighted regression.

4. DATA COLLECTION

Twenty-one signalized intersections across the state of Indiana were selected for our study. Three criteria were considered in the selection:

(1) Long queues,
(2) Base conditions, and
(3) Population.

Sufficiently long queues are required to observe saturated flow conditions. As pointed out by Le et al. (3), the intersections must include lanes operating under base conditions (12-ft lanes, no pedestrian flow, no parking maneuvers, no bus stops, and zero grade approach). A low percentage of heavy vehicles is acceptable as it can to be accounted for when estimating the base saturation flow rate. Diversified population sizes and other local conditions must be reflected in the sample to investigate their effect. Table 1 shows the communities selected for the study. Only Indianapolis has been classified as a large community. Communities with a population of more than 20,000 were classified as medium. Small communities were defined as those with a population of less than 20,000 inhabitants. Table 1 presents the selected towns and their population.

A mobile traffic laboratory was used to record traffic queues and signal displays at the studied intersections (see Fig. 1). A digital video recorder and cameras on a 45-ft mast were used for this
purpose. The mobile traffic laboratory was parked near the intersection where traffic operations were not affected by its presence. The typical data collection setup is presented in Figure 2. The cameras on the mast were used to record traffic discharging from at least two approaches. We attempted to have entire queues in the field of view. In some cases, however, the end of the queue was outside of the field of view. These images did not allow for measuring the queues and delays but were still useful for measuring the saturation flow rates. The additional two cameras on tripods were used to record displayed signals. The digital video recorder was used to simultaneously record the video streams from the four cameras.

The four video streams were mixed in a multiplexer and displayed as one image to synchronize and ease the measurements during the playback (Fig. 3). An Excel-based software and spreadsheet forms were used to record the data. The following quantities were measured with the video images:

- $T_G$ Time when green phase starts
- $T_4$ Time when 4th vehicle’s front axle crosses the stop bar
- $T_q$ Time when saturation ends
- $T_y$ Time when yellow phase ends
- $n_{hv1}$ Number of heavy vehicles in start-up discharge
- $n_{pc2}$ Number of passenger vehicles in saturated discharge
- $n_{hv2}$ Number of heavy vehicles in saturated discharge

Vehicles departing from the queue included those stopped on the approach and those that joined the queue before the stop-bar when the end of the queue was already moving. Cycles with at least five vehicles were used for the estimation of saturation flow rate. Those cycles with exactly four vehicles were included for the estimation of start-up lost time. The first four vehicles in the queue from then on were referred as start-up discharge while those vehicles between the fifth and the last in a queue were referred as saturated discharge. Other measurements of great importance were the length of the yellow and all-red periods (clearance period).

Using field measurements and a spreadsheet, the following values were calculated for every cycle:

Start-up discharge time, $t_4 = T_4 - T_G$
Saturated discharge time, \( t_s = T_q - T_d \)

Green time extension, \( e = T_q - (T_y - A) \)

Number of passenger vehicles in the start-up discharge, \( n_{pc1} = 4 - n_{hv1} \)

The saturated discharge time and the number of passenger and heavy vehicles in the saturated discharge were used to estimate the saturation flow rate. The start-up discharge time was used to estimate the start-up lost time. These calculations are explained in the next section.

5. ESTIMATION OF CAPACITY PARAMETERS

The capacity parameters were estimated using the following model:

\[
    t_s = h_{pc} \cdot n_{pc2} + h_{hv} \cdot n_{hv2}
\]

where:

- \( t_s \) = saturated discharge time,
- \( n_{pc2} \) = number of passenger vehicles in the saturated discharge,
- \( n_{hv2} \) = number of heavy vehicles in the saturated discharge,
- \( h_{pc} \) = estimated saturated headway for a passenger vehicle in seconds (regression parameter),
- \( h_{hv} \) = estimated saturated headway for a heavy vehicle in seconds (regression parameter).

The regression parameters were estimated using the regression procedure of the Statistical Analysis System (SAS) Computer Program Package (15). The parameters represent the average saturated headways for passenger and heavy vehicles. Table 2 shows example results for the westbound through lanes at the intersection of US 36 and Girls School Road in Indianapolis, Indiana. The presented values were obtained based on data collected in 33 cycles. Equations 2-7 were used to calculate the saturation flow rate, passenger car equivalency factor, lost time, and corresponding estimation errors.

Estimates of the saturation flow rates \( s \), the passenger car equivalency factor \( E \), and the corresponding variances (standard deviations) were calculated for each traffic lane using the regression results and the following equations (symbol “\( \sim \)” signifies an estimate):
\[ \tilde{s} = \frac{3600}{h_{pc}} \]  

\[ \text{var} \tilde{s} = \left( \frac{3600}{h_{pc}^2} \right)^2 \sigma_{pc}^2 \]  

\[ \tilde{E} = \frac{\tilde{h}_{hv}}{h_{pc}} \]  

\[ \text{var} \tilde{E} = \text{var} \left( \frac{\tilde{h}_{hv}}{h_{pc}} \right) = \left( \frac{1}{h_{pc}} \right)^2 \sigma_{hv}^2 + \left( \frac{h_{hv}}{h_{pc}^2} \right)^2 \sigma_{pc}^2 \]  

The start-up lost time estimate \( \tilde{t}_i \) is calculated from the estimated saturated headway, which is the time at the beginning of the green phase that is not effectively used. It is calculated as the difference between the average start-up discharge time \( \tilde{t}_4 \) (no heavy vehicles) and the average saturated discharge time of four passenger cars:

\[ \tilde{t}_4 = \tilde{t}_4 - 4h_{pc} \]  

The variance of the estimated start-up lost time includes the variance of \( \tilde{t}_i \) estimate and the variance of the saturated headway estimate:

\[ \text{var} \tilde{t}_4 = \text{var} t_4 + 16 \sigma_{pc}^2 \]  

Example estimates of the saturation flow rate and other capacity parameters obtained from the results presented in Table 2 are shown in Table 3.

The HCM defines the extension of the effective green time \((e)\) as “The amount of the change and clearance interval, at the end of the phase for a lane group that is usable for movement of its vehicles.” Also, it defines the change and clearance interval as “The yellow plus all-red interval...
that occurs between phases of a traffic signal to provide for clearance of the intersection before conflicting movements are released.” To be consistent with the HCM notation, letter Y will be used for the length of the change and clearance interval. Letter A will stand for the length of the yellow (amber) signal.

The effective green extension time was calculated using the time when the front axle of the last vehicle in a saturated queue crosses the stop bar and the time when the displayed green phase ends as shown in Equation 8:

\[ e = T_q - (T_y - A) \]  

(8)

Forty-three through lanes and twelve exclusive left-turn movements were included in the study. Table 4 and Table 5 show a summary of the average values of the capacity parameters. Estimation accuracy was considered when calculating the averages by weighting the individual results with the inverse of the estimate variance. The heavy vehicle equivalency factor average value for the through movement was estimated based on 28 lanes with heavy vehicles present.

Although the average value for the saturation flow rate is slightly below the HCM-recommended value, the variability between locations is quite strong and cannot be explained with the measurement error. Small communities tend to have considerably lower values of saturation flow rates than large communities. Table 4 shows that the green time extension is one second longer than the start-up lost time, which means that an effective green is one second longer than a displayed green. The average value of start-up lost time is close to the default of two seconds recommended by the HCM 2000. Also, the heavy vehicle equivalency factor is not significantly different from the default value of two. Although the lost time and equivalency factor estimates vary considerably across traffic lanes and intersections, the preliminary inspection of the results did not reveal any obvious trends. Most of the variability of these estimates can be attributed to the considerable measurement error. All the parameters will be further studied to identify sources of their variability.
The estimates of the average saturation flow rates for through and left-turn movements are close. It should be stressed, however, that exclusive left-turn lanes were not present at the studied intersections in small communities. A comparison of the average saturation flow rates measured in medium towns and in Indianapolis indicated that the base saturation flow rate for left-turn movements was, on average, 95% of the values for through movements, which is the default value recommended in the HCM.

6. VARIABILITY OF CAPACITY PARAMETERS

The considerable variability of capacity parameter estimates across sites prompted studying the effects of several local characteristics considered to be good candidates of capacity factors: population, road class, number of lanes, and right-most through lane design. These characteristics are shortly discussed.

*Population* – Previous studies indicated that community size had an effect on capacity. It seems that drivers in large communities are more aggressive than drivers in small communities. To investigate this effect, the developed areas in Indiana were classified in three categories: small, medium, and large. The only exception was small towns located outside of the Indianapolis city limits but within driving distance to the Indianapolis downtown. These communities were considered part of the metropolitan area because a majority of their drivers commute to Indianapolis and exhibit the large city driving style.

*Road Class* – The effect of road class on the capacity parameters was investigated. The function of each class may exhibit correlation with the percent of non-commuters present in the traffic flow. Arterials and US/State routes tend to have more non-commuters (drivers unfamiliar with the road) than local roads.

*Right-most lane* – The studied intersections have lane groups with one, two, or three lanes. Heavy vehicles use right lanes more frequently than other lanes. It is also possible that less aggressive drivers tend to use the far right lane. If any effect is found, lane groups with more than
one lane would be representative of medium and large size towns, due to the absence of this scenario in small towns.

Curb – The effect of geometric conditions to the right of the far right lane was also evaluated. It is possible that the presence of curb and inlets may reduce the saturation flow rate.

Lane Volume – Lane volume has been considered in previous research as a factor that might increase the saturation flow rate, especially among the first vehicles in a queue. The numbers of vehicles that exited the studied intersections in cycles used to estimate saturation flow rates were converted to lane hourly volumes.

For the analysis, the base case scenario was defined as a single lane approach, on an arterial road located in a large size town, with an exclusive right-turn lane to the right side of the lane.

A weighted regression analysis was used to account for varying precision of the saturation flow estimates. The following model was applied to the saturation flow rate estimates for through lanes:

\[ s = s_0 + a_m \cdot m + a_{sm} \cdot sm + a_{rl} \cdot rl + a_c \cdot c + a_{co} \cdot co + a_l \cdot l + a_{lv} \cdot lv, \]  

(9)

where:
- \( s \) = base saturation flow rate
- \( s_0 \) = base saturation flow rate for the base case scenario
- \( m = 1 \) if medium size town, otherwise 0
- \( sm = 1 \) if small size town, otherwise 0
- \( rl = 1 \) if rightmost lane, otherwise 0
- \( c = 1 \) if curb present at right side border of right-most lane, otherwise
- \( co = 1 \) if collector road, otherwise 0
- \( l = 1 \) if local road, otherwise 0
- \( lv = \) hourly volume for particular lane

The categorical factors were investigated with the SAS regression procedure (PROC REG). The estimation of the saturation flow rate for each lane was based on a determined number of cycles, different for each lane. Two types of errors are present in the saturation flow estimate obtained from the model, the disturbance term and the measurement error. The disturbance term is caused
by factors not included in the model. The measurement error is caused by the imperfection of the measurement method and the limited size of the sample. To account for this error, weighted linear regression was used with weights equal to the inverse of the squared measurement error.

All model variables included in Equation 9 were tested for statistical significance. The insignificant variables were removed from the model, namely, road class, presence of curb, and hourly lane volume. The model specification is shown in Table 6.

The final model is:

\[ s = 2051 - 163 \cdot m - 423 \cdot sm - 88 \cdot rl \]  

(10)

The regression analysis indicates that the community size and the right-most position of the lane in the lane group significantly affect the saturation flow rate. Figure 4 compares the predicted values for the saturation flow rate with the measured values.

Equation 10 indicates that the base saturation flow rate in a medium town is lower by 163 veh/h/lane than in a large town. This corresponds to an 8% reduction. The reduction of the base saturation flow rate in a small town if even larger and it equals 423 pc/h/lane or 21%. These findings are consistent with the study results obtained for other regions by Zeeger (15) and Agent and Crabtree (16) as shown in Table 8.

The base saturation flow rate model in Equation 10 applies to a traffic lane. It has been converted to a model of base saturation flow rate for a lane group by averaging base saturation flow rates across lanes in the lane group: \( s = \Sigma s_i/n \), where \( s_i \) is the base saturation flow rate in lane \( i \) calculated in Equation 10 and \( n \) is the number of lanes in the lane group. The new equation is:

\[ s = 2051 - 163 \cdot m - 423 \cdot sm - \frac{88}{n} \]  

(11)

where:

\( s = \) base saturation flow rate for lane group
The model is recommended for Indiana to replace the default value of 1900 veh/h/lane. Table 7 presents the values for various local conditions rounded to nearest tens.

6. CONCLUSIONS

The Indiana-average saturation flow rate, lost time, heavy vehicle equivalency factor, and adjustment factor for protected left turns were found to be close to the default values recommended in the HCM manual.

Although the Indiana typical values of capacity parameters conform to those recommended by HCM 2000, the variability across locations was considerable. Not all of this variability could be explained with the limited measurement precision, but it was obvious for the saturation flow rates. The size of the community was found to be very significant both from a statistical and a practical viewpoint. The saturation flow rates in Indianapolis were higher than in small towns by 423 veh/hour/lane. Also, the far right lane exhibited saturation flow rates 88 veh/h lower than other through lanes. This difference can be explained by the presence of less aggressive drivers who prefer using these lanes. Also, worse pavement conditions in this lane (inlets, gutters, etc.) may play some role.

Saturation flow rates in medium towns have been found 8% lower than in large towns. This difference is even larger for small towns where it is 21%. These findings are consistent with the previous studies for other regions. Past research on the delay sensitivity on saturation flow inaccuracies allows concluding that the revealed overstatement of the saturation flow rates in the current HCM method must lead to a considerable underestimation of delay when the v/c ratio is higher than 0.9. A saturation flow adjustment factor for population is needed. A saturation flow adjustment factors of 0.92 for medium towns and 0.79 for small towns are proposed to account for the population size effect.
The variability of start-up lost time was investigated and analyzed. No significant factors across locations could be found. Other factors might be considered in future research to accomplish this task. The average value for green extension was calculated; and it was approximately one second longer than the start-up lost time. This finding indicates that an effective green signal tends to be one second longer than the displayed green, confirming the recommendations of the early edition of the HCM (1), which recommends the use of effective greens equal to the displayed signals.

Further research is needed to estimate the typical values of PHF and to identify the PHF factors. The size of the town and the traffic intensity are among good candidates.

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Table 1. Communities Selected for study

<table>
<thead>
<tr>
<th>COUNTY</th>
<th>CITY/TOWN</th>
<th>POPULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fountain</td>
<td>Attica</td>
<td>3,491</td>
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<td>Parke</td>
<td>Rockville</td>
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<td>Owen</td>
<td>Spencer</td>
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<td>Hendricks</td>
<td>Avon</td>
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<td>Hamilton</td>
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<td>Indianapolis</td>
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<td>White</td>
<td>Monticello</td>
<td>5,723</td>
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</table>

Note (1) – Location in close vicinity to Indianapolis
### Table 2: Saturated Headways at US 36 & Girls School Road

| Variable | DF | Parameter | Standard Error | t Value | Pr > |t| | 95% Confidence Limits |
|----------|----|-----------|----------------|---------|------|----------------|-----------------------|
|          |    | Estimate  |                |         |      |               |                       |
| $h_{pc}$ | 1  | 1.826     | 0.037          | 48.5    | <.0001| 1.75           | 1.90                  |
| $h_{hv}$ | 1  | 4.198     | 0.427          | 9.8     | <.0001| 3.33           | 5.07                  |
Table 3 Capacity Parameter Estimates (US 36 & Girls School Rd)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Heavy Vehicle Equivalency Factor</td>
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<td>Start-up Lost Time (sec)</td>
<td>2.34</td>
<td>0.26</td>
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<td>Sat Flow Rate (pcphgpl)</td>
<td>1971</td>
<td>41</td>
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Table 4 Capacity Parameters for Through Movement

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average Value</th>
<th>Min Value – Max Value</th>
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<tr>
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<td>1352 - 2178</td>
<td>199</td>
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<td>Heavy Vehicle Equivalency Factor</td>
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<td>1.41 – 4.15</td>
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<tr>
<td>(^{(2)}) Green Time Extension (sec)</td>
<td>2.81</td>
<td>0.03 – 5.83</td>
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\(^{(2)}\) Including through and left turn movements
Table 5 Capacity Parameters for Left Turn Movements \(^{(3)}\)

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<tr>
<th>Parameter</th>
<th>Weighted Average Value</th>
<th>Min – Max Values</th>
<th>Standard Deviation</th>
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<td>1764 - 2079</td>
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<td>Start-up Lost Time (sec)</td>
<td>1.61</td>
<td>0.57 – 2.91</td>
<td>0.71</td>
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<tr>
<td>Heavy Vehicle Equivalency Factor</td>
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<td>1.45 – 2.98</td>
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\(^{(3)}\) Small size towns not included
Table 6 Parameter Estimate Using Weighted Linear Regression *(revise)*

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Parameter Estimate</th>
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<th>95% Confidence Limits</th>
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*R^2 = 0.75*
Table 7. Recommended Base Saturation Flow Rate

<table>
<thead>
<tr>
<th>Number of Lanes</th>
<th>Population</th>
<th>Population</th>
<th>Indianapolis</th>
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<tr>
<td></td>
<td>&lt; 20 thousands</td>
<td>20 to 100 thousands</td>
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<td>1</td>
<td>1540</td>
<td>1800</td>
<td>1960</td>
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<td>2</td>
<td>1580</td>
<td>1840</td>
<td>2010</td>
</tr>
<tr>
<td>3</td>
<td>1600</td>
<td>1860</td>
<td>2020</td>
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Table 8 Comparison of research results on the impact of the population size on the saturation flow rate (in reference to a big town of population larger than 100,000)

<table>
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<th>Study</th>
<th>Study Areas</th>
<th>Small Town</th>
<th>Medium Town</th>
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<tr>
<td></td>
<td>Population</td>
<td>Reduction</td>
<td>Population</td>
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<tr>
<td>Agent and Crabtree, 1982</td>
<td>Kentucky</td>
<td>&lt;20,000</td>
<td>20,000 – 50,000</td>
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<td>Zegeer, J, 1986</td>
<td>Chicago, Houston, Los Angeles</td>
<td>Not determined</td>
<td>50,000 – 100,000</td>
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<tr>
<td>Perez-Cartagena and Tarko, 2004</td>
<td>Indiana</td>
<td>&lt;20,000</td>
<td>20,000 – 100,000</td>
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</tbody>
</table>
Figure 1 The Mobile Traffic Laboratory
Figure 2 Field Data Collection Set-up
Figure 3 Field Data Collection Screen View (US 36 & Girls School Rd, Indianapolis, IN)
Figure 4 Comparison between Measured and Predicted Base Saturation Flow Rate